Annual Subscription Price, $4. 130 *Published Ten Times a Year.*

Astronomy

AND

Astro-Physics

EDITORS:

WM. W. PAYNE. GEORGE E. HALE.

ASSOCIATE EDITORS:

S. W. BURNHAM. JAMES E. KEELER.
E. E. BARNARD. HENRY CREW.
H. C. WILSON JOSEPH S. AMES.

DECEMBER, 1894.

CONTENTS:

GENERAL ASTRONOMY:

Frontispiece. **Photograph of Brooks' Comet, 1893, Nov. 10.** Plate XXXV. *E. E. Barnard*..... 789

Photograph of M8 and the Trifid Nebula. Plate XXXVa. *E. E. Barnard*..... 791

The Astrolabe. Plates XXXVI-XL. *Margaret L. Huggins*..... 793

On the Quadruple Star ζ Cancri. *Professor Seeliger*..... 802

The Great Photographic Nebula of Orion Encircling the Belt and Theta Nebula. Plate XLI. *E. E. Barnard*..... 811

Mars. Plate XLII. *Percival Lowell*..... 814

The Form of the Disc of the III Satellite and Phenomena of the Occultation of a Satellite of Jupiter. *E. E. Barnard*..... 821

The Distribution of the Heat of the Sun. *W. H. S. Monck*..... 823

The Twenty-inch Equatorial of the Chamberlin Observatory. *H. A. Howe*..... 826

ASTRO-PHYSICS:

The Astrophysical Journal. *George E. Hale*..... 831

The Modern Spectroscope. IX. Fixed-arm Spectroscopes. Plates XLIII-XLV. *F. L. O. Wadsworth*..... 835

On Brester's Views as to the **Tranquillity of the Solar Atmosphere.** *A. Brester, Jr.*..... 849

ASTRO-PHYSICAL NOTES..... 856

CURRENT CELESTIAL PHENOMENA..... 862

NEWS AND NOTES..... 871

General Index for Vol. XIII, 1894..... 873

OFFICE OF PUBLICATION:

CARLETON COLLEGE, NORTHFIELD, MINN.

Wm. Wesley & Son, 28 Essex St. Strand, London, are foreign agents.

Entered at the PostOffice at Northfield, Minn., for transmission through the mails at second classrates.

J. A. BRASHEAR,

ALLEGHENY, PA.,

MANUFACTURER OF

REFRACTING TELESCOPES

SILVERED GLASS

Reflecting Telescopes

AND SPECULA.

Visual and Photographic Objectives

Of the Highest Excellence
With urves computed by Dr. C. S. Hastings
Of Yale Universitv.

Plane Mirrors of Speculum Metal or Glass for all purposes of Scientific Research.

Parallel Plates, Prisms of Glass, Quartz, or Rock Salt with surfaces warranted flat.

Eye-pieces of all kinds, including our Improved Polarizing Eye Piece for Solar observations, and Solid Eye Pieces for high powers.

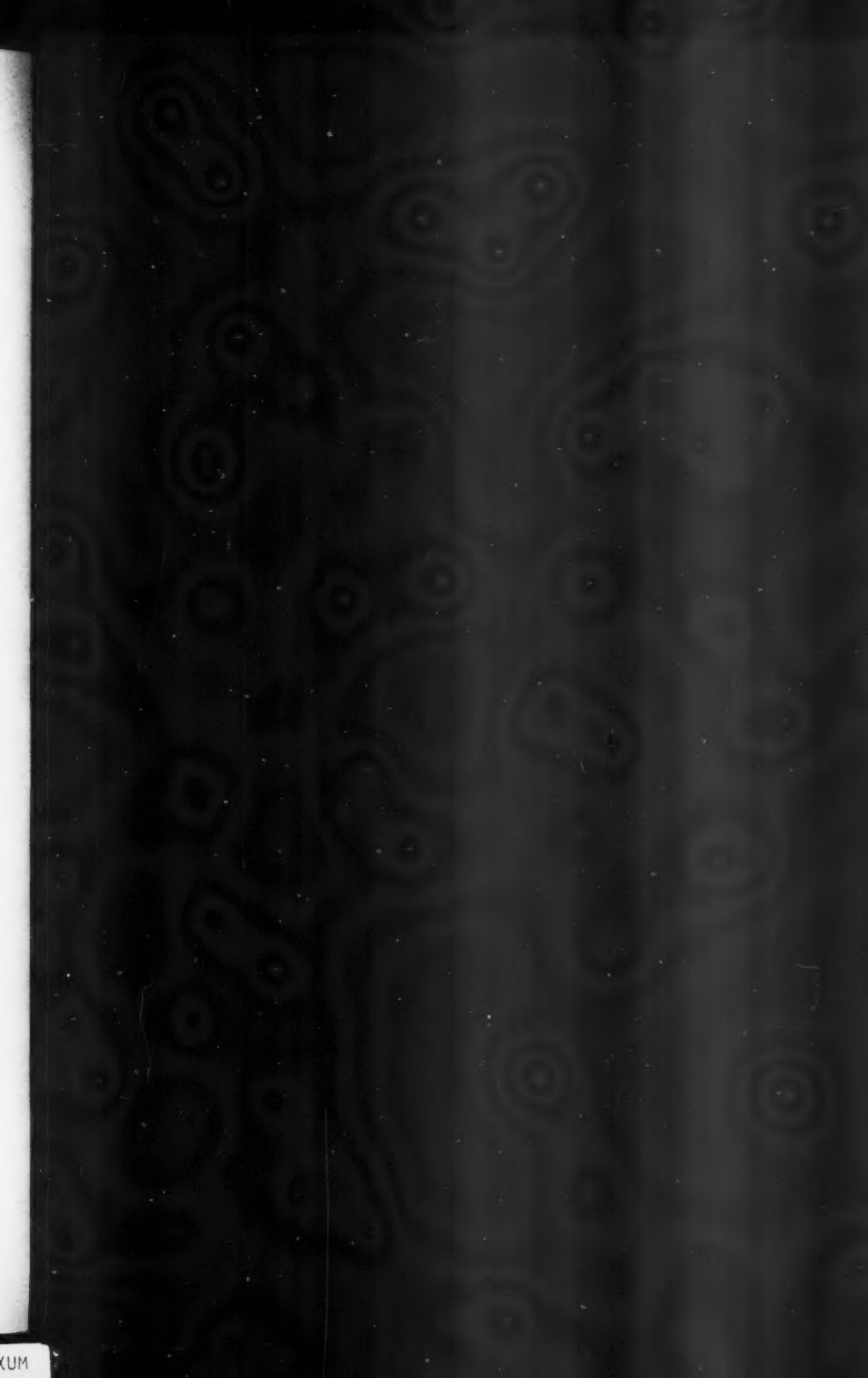
Diffraction Gratings ruled on Prof. Rowland's Engine from one to six inches diameter, and ruled with 14,000 to 75,000 lines.

Spectroscopes of all kinds, including Telespectroscopes and Concave Grating Spectroscopes with photographic attach ent.

"Comet Sweepers," Micrometers, Driving Clocks, Heliostats, Siderostats.

Special Apparatus for physical or astronomical research, designed and constructed.

XUM



XUM

A Weekly Feast to Nourish Hungry Minds.—N. Y. Evangelist.

LITTELL'S LIVING AGE.

1844—1895

Over half a century has passed since its first number appeared, and now, as it enters its **52d year**, it still maintains the high standard of literary excellence which has characterized it from the beginning.

OBSERVE! **The Living Age is a Weekly Magazine** giving fifty-two numbers of sixty-four pages each, or more than **Three and a Quarter Thousand** double-column octavo pages of reading matter yearly, forming **four large volumes** filled with the ripest thought of

THE ABLEST MINDS OF THE AGE,

and presenting a mass of matter **Unequalled in Quality and Quantity** by any other periodical. It presents in convenient form a compilation of the world's choicest literature, Encyclopedic in its Scope, Character, Comprehensiveness and Completeness, and with a freshness, owing to its frequent issue, attempted by no other publication.

Ablest Essays and Reviews,	**Biographical Sketches,**
Latest Results of Scientific Research,	**Literary Criticism,**
Stories of Travel and Exploration,	**Fiction,**
Every Phase of Culture and Progress in the European World.	

INDISPENSABLE to every one who wishes to keep pace with the events of intellectual progress of the time, or to cultivate in one's self or one's family general intelligence and literary taste.

A NEW SERIES was begun with the first number of its 200th Volume, January 1st, 1894. With it were begun entirely new tales, already embracing three *Copyrighted Serials*, from the pens of noted French and German novelists; and shorter stories by prominent foreign authors. Below are named some of the many eminent authors already represented in this, the sixth, series.

Rt. Hon W. E. GLADSTONE,	Prof. HUXLEY, F.R S.	Gen'l Sir ARCH'LD ALISON, G.C.B.
Prof. VAMBERY,	Prince PAUL KROPOTKIN,	Sir ROBERT BALL, F. R. S.
W. H. MALLOCK,	PAUL PERRET, (French)	REGINALD B. BRETT,
Countess COWPER,	FRANK E. BEDDARD, F.R.S.	ERNST ECKSTEIN, (German.)
LESLIE STEPHEN,	BEATRICE HARRADEN,	WM. CONNOR SYDNEY,
FREDERIC HARRISON,	Mrs. ANDREW CROSSE,	W. W. STORY.
J. P. MAHAFFY,	MULJI DEVJI VEDANT,	Sir BENJ. BAKER, K. C. M. G.
ANDREW LANG,	CHARLES EDWARDES,	Sir HERBERT MAXWELL,
WALTER PATER,	J. NORMAN LOCKYER,	Count LEO TOLSTOI,
FRIDTJOF NANSEN,	CHRISTINA G. ROSSETTI,	The ABBE PREVOST, (French)

With the steady improvement in all lines of trade and commerce, and increased confidence in financial circles, the publishers anticipate a large gain over the past year. To aid in its realization and to furnish to every lover of choice literature the strongest possible inducement to become a reader of **THE LIVING AGE**, is made the following

ADVANTAGEOUS OFFER TO NEW SUBSCRIBERS.

To each NEW Subscriber NOW remitting $8.00, for the year 1895, will be sent

ABSOLUTELY FREE,

The Thirteen Weekly Issues of The Living Age, forming the last quarterly volume of 1894, (October, November, December,)

AND

A Year's Subscription to any one of the following publications:

The Cosmopolitan,	**National Popular Review,**
Domestic Monthly,	**The Pulpit,**
Electric Power,	**N. Y. (Weekly) Sun,**
McClure's Magazine	**Springfield (Weekly) Republican,**
Midland Monthly,	**N. Y. (Weekly) Mail and Express,**
The Etude,	**Boston (Weekly) Transcript,**
Godey's Magazine,	**Boston (Weekly) Journal,**
American Teacher,	**Weekly Courier Journal,**
S. S. Times,	**Weekly Detroit Press,**
Golden Rule,	**N. Y. (Weekly) Post,**

or a **6 months** subscription to **Scribner's Magazine.**

Or, to **new subscribers** preferring to begin with the first issue of the **New Series** (as above), and have it complete, the numbers (104) of the **two years,** 1894 and 1895, will be sent, postpaid, for only **$10.**

THE LIVING AGE is published **Weekly** at $8.00 a year, free of postage.

Rates for clubbing THE LIVING AGE with more than one other periodical will be sent on application. Sample copies of THE LIVING AGE, 15 cents each.

Address, **LITTELL & CO., 31 Bedford St., Boston.**

XUM

—THE—

CHICAGO,

MILWAUKEE &

ST. PAUL R'Y

With its 6,100 miles of thoroughly equipped road reaches all principal points in

Northern Illinois, Wisconsin, Iowa, Minnesota, South Dakota, North Dakota and Northern Michigan.

THE ONLY LINE

Running Electric Lighted and Steam Heated Vestibuled Trains.

All Coupon Ticket Agents in the United States and Canada sell tickets via the Chicago, Milwaukee & St. Paul R'y.

GEO. H. HEAFFORD,

Genl. Pass. Agent, Chicago, Ill.

XUM

PRICE SIXPENCE, MONTHLY

Knowledge: An Illustrated Magazine of Science.

PLAINLY WORDED
AND EXACTLY DESCRIBED. . .

:: EDITED BY ::

A. COWPER RANYARD, M. A., F. R. A. S.

"KNOWLEDGE" contains Reviews and Articles explaining, in simple untechnical language, recent researches in Astronomy, Natural History, Physics and Physical Geography, Geology, and Botany. Each number contains one or more full-page photographic reproductions of some object of scientific interest, as seen with the Telescope, the Microscope, or the ordinary Camera, so that the reader is brought as nearly as possible into the presence of the objects described, and the mental images formed are likely to be more accurate than if derived from pictures drawn by the most careful artists. . . .

> . . . Ordinary woodcuts and blocks are, however, not dispensed with, but are freely used, in addition to the photographic illustrations, whenever it is thought they will make the meaning more clear.

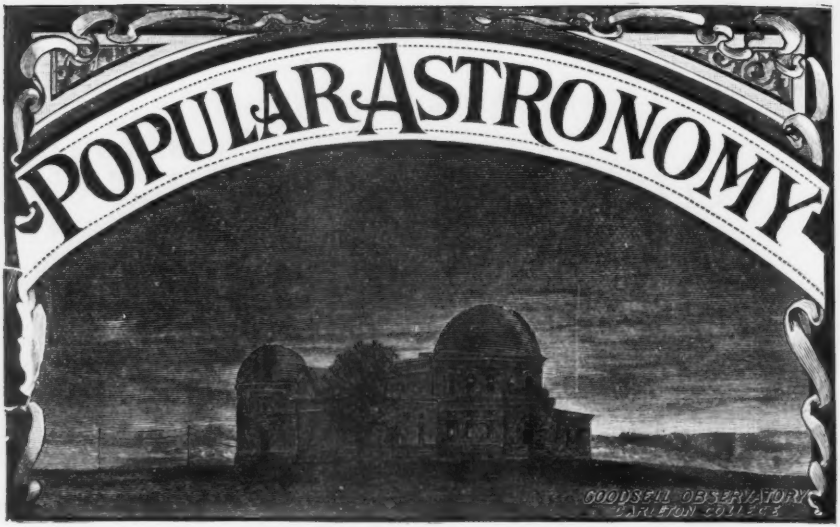
Amongst the writers who have contributed to the pages of "KNOWLEDGE" since the death of the late Mr. R. A. PROCTOR, in September, 1888, may be mentioned Prof. J. C. Adams, Sir G. B. Stokes, Prof. Pickering, Prof. Young, Mr. Burnham, Prof. Asaph Hall, Mr. Grant Allen, Lord Grimthorpe, Canon Isaac Taylor, Mr. E. A. Butler, Mr. E. Clodd, Mr. R. Lydekker, Mr. Isaac Roberts, Mr. G. J. Symons, Mr. Herbert Sadler, and Mr. Mattieu Williams.

To be had of all Booksellers, or direct from the Printing and Publishing Office of KNOWLEDGE,

326, HIGH HOLBORN, LONDON, W. C.

AMERICAN AGENTS:

NEW YORK (U. S. A.)—The International News Company, 83 and 85 Duane Street.
TORONTO (Canada)—The Toronto News Company.
MONTREAL (Canada)—The Montreal News Company.



HE STRETCHETH OUT THE NORTH OVER THE EMPTY PLACE, AND HANGETH THE EARTH ON NOTHING.

A NEW ASTRONOMICAL PERIODICAL

DESIGNED FOR AMATEURS, TEACHERS, STUDENTS OF ASTRONOMY AND POPULAR READERS.

Plainly Worded and Untechnical in Language. Amply Illustrated.

Issued Monthly except July and September. Subscription Price $2.50 in advance: for Foreign subscribers 14 shillings.

CONTENTS FOR DECEMBER, 1894.

Frontispiece. (Plate XIII).
The Planet Jupiter. (Illustrated). *G. W. Hough* 145
The Great Photographic Nebula of Orion, Encircling the Belt and Theta Nebula. (Plate XIV). *E. E. Barnard* 151
Mars: Atmosphere. *Percival Lowell* 154
On the Variable Stars of Short Period. (Illustrated). *P. S. Yendell* 160
Observations of the Transit of Mercury, 1894, Nov. 9-10 168
Progress of Astronomical Photography. *H. C. Russell* 170
Occultation of the Pleiades December 10-11. (Plate XV). *H. C. Wilson* 176
Planet Notes and Tables. *H. C. Wilson* 181
Transit of Mercury Notes 185
Comet Notes 189
Practical Suggestions 189
General Notes 191
Publisher's Notices.
Star Map for December 1894. (Plate XVI).

EDITORS:
WILLIAM W. PAYNE, CHARLOTTE R. WILLARD,
GOODSELL OBSERVATORY OF CARLETON COLLEGE,
NORTHFIELD, MINNESOTA, U. S. A.

Wm. Wesley & Son, 28 Essex St. Strand, London, are sole European agents.

XUM

PLATE XXXV.

N

S

PHOTOGRAPH OF BROOKS' COMET.

1893, Nov. 10. $15^h\ 35^m - 17^h\ 35^m$ Pacific Standard time. Made with the 6-inch Willard lens of Lick Observatory.

XUM

Astronomy and Astro-Physics.

VOL. XIII, No. 10. DECEMBER, 1894. WHOLE No. 130.

General Astronomy.

PHOTOGRAPHS OF A REMARKABLE COMET.*

E. E. BARNARD.

Mr. Ranyard has published in the February 1894 number of *Knowledge*, two photographs of the set which I obtained of Brooks' October, 1893, Comet.

These two were made on the dates October 21 and 22. They show the remarkable disturbance which utterly transformed the tail of the comet in the 24 hours intervening between the two pictures.

In the May number of the same journal, Mr. Ranyard has again reproduced an admirable enlargement of the picture of October 21.

Of the set of fifteen nights' photographs, these two are perhaps the most startling pictures. Many of the others, however, are extremely remarkable and some are very beautiful. One of these, on November 10th, though it does not present any startling features, is nevertheless so gracefully beautiful that I have thought the readers of ASTRONOMY AND ASTRO-PHYSICS would be interested in seeing it. I have, therefore, made an enlargement of it which accompanies this article.

This enlargement is $2\frac{1}{10}$ times the original size, and is on the scale of about 0°.9 to one inch.

In this picture it will be noticed that the star trails (produced by making the telescope move with the comet) are very irregular and broken. The comet was faint in the guiding telescope and no nucleus could be seen to guide by, so that it was impossible to accurately follow its motion; this, however, does not effect the image of the comet itself.

In the present photograph the phenomena apparently seem to be due to peculiarities of emission from the nucleus alone. The head is small and round, with a slender neck-like tail that branches out into three beautiful fan-like streams some 18′ from the head.

* Communicated by the author.

XUM

The central stream forms the main tail which can be traced for six degrees or more. This tail is clouded here and there with unequal masses of matter. A prominent one of these masses will be noticed nearly 3° back from the head. Beyond this the tail fades out rapidly and 4½° from the head is almost discontinuous, beyond this weak spot it again brightens up as a prominent elongated mass almost wholly detached from the tail. A similar mass to this is shown on several dates—especially on November 11th and 12th completely detached from the tail and which may be the same object of November 10.

On the plate of November 6, a large mass one degree long is shown about 6° from the head and completely detached from the tail.

There are many other interesting and important features shown on the various photographs, each one of which would be in itself a study, but at present, until I can place all these pictures properly before astronomers, it is not possible to go into details concerning them.

Though this comet was a small affair visually, and apparently of little consequence beside many of the great comets of recent years, it unquestionably far exceeded any of them in the richness of the phenomena it photographically presented.

It seems to have been passed unnoticed by photographic astronomers elsewhere, which makes the Lick Observatory set absolutely priceless.

Like Swift's comet of 1892 the photographs of this object mark an epoch in cometary photography as decisive as it is important.

In reference to the remarkable shattering of the tail of this comet as shown on the photographs of Oct. 21 and 22, I have suggested that this might be due to an encounter of the tail with some kind of resisting medium—a cosmical cloud—a swarm of meteors—certainly a region of resistance of some form. I still firmly adhere to this supposition. Mr. Ranyard, however, in an interesting and important article on "Irregularities in the Tails of Comets" in the February *Knowledge* referred to, presents other explanations that in the main seem to me to very satisfactorily account for the appearances of the tail; but he also assumes a resisting medium and differs from me principally in the manner in which he supposed this medium to act on the comet.

As his remarks will bear upon many of the phenomena of comets I will here quote a portion of his paper.

"* * * Professor Barnard has noticed the detached cloud com-

XUM

pletely separated from the end of the tail on the 22d of October, and the rest of the tail in the photograph taken on the 22d of October is broken into fragments, indicating short spasmotic outbursts, during which matter must have been driven away in considerable quantities from the nucleus, followed by quieter intervals.

That these outbursts were of comparatively short duration is, I think, proved by the slight curvature of the tail, which indicates that the motion of the nucleus was not considerable during the time occupied by the passage of matter from the nucleus to the end of the tail.

On the other hand, the velocity of the matter of the tail away from the nucleus, does not seem to have been sufficiently great to disturb the definition of the notches on the edge of the tail in the thirty-five minutes during which the photograph was exposed, on the 21st of October.

Such rapid changes in the amount of matter driven away from the nucleus would seem to point to an irregular evolution of energy, such as might be caused by the passage of the nucleus through an irregularly distributed resisting medium, rather than to the evaporation of matter due to a steady increase of heat on approaching the Sun.

The notches and irregularities in the edge of the tail, as well as the branching structures in the photograph of the 21st of October, seem to me to point to outrushes of matter from the nucleus through a resisting medium, in different directiors, which outrushing matter has afterwards been driven away from the Sun, rather than to a disturbance of the regular form of cometary tail due to an encounter of the matter in the tail with a resisting medium at a distance from the nucleus.* * *"

At the request of M. Bredichin, Director of the Pulkowa Observatory, a full set of the photographs of this comet has been sent to him by the Lick Observatory through the courtesy of the Smithsonian Institution. M. Bredichin wishes to see how far the phenomena of this comet's tail will conform to his theories.

A set has also been sent to the Royal Astronomical Society.

PHOTOGRAPH OF M 8, AND THE TRIFID NEBULA.*

E. E. BARNARD.

In lapping my photographs in the southern part of the Milky Way, I have repeatedly secured impressions of the Trifid nebula

* Communicated by the author.

and M8. The latter object which is seldom mentioned, is far more remarkable than the celebrated trifid. It is a great mass of nebulosity mixed up with many bright stars and is a beautiful object in a good telescope—the stars shining freely in the nebulosity, and especially rich in the following and fainter portion. The nebulosity is heaviest preceding the center. In the following part of the nebula is a conspicuous star on the following edge of a small very black hole.

The impressions of M8, and the trifid have always happened to fall near the edge of the plates, as I was not intent on getting a picture of the nebulæ but to secure impressions of the star clouds of the Milky Way in this region.

I have selected the best image among these of the two nebulæ and have made an enlargement of it, which accompanies this paper. As the nebulæ are to one side of the plate the stars are not round but are elongated by the distortion of the field.

In this enlargement M8 is shown to be a very singular object—an unequally condensed mass of nebulosity mixed with many bright stars. Its southern edge is singularly well defined with several saw tooth-like projections. The small star and the dark hole in the following part of the nebula are well shown.

In a paper dated 1892, July 8, on "Photographic Nebulosities and Groups of Nebulous Stars" which was printed in *Astr. Nach.* No. 3111, I have called attention to the appearance of M8 on these photographs.

"The singular mixture of stars and nebulosity, M8, is shown on several of the photographs and is a very remarkable object. East and west its diameter is about 45′ and north and south some 42′. The southern side is sharply defined and serrated with three distinct pointed projections. From its north following corner a wisp of nebulosity extends nearly to the group of nebulous stars just mentioned, and possibly with a longer exposure, would be found to connect with them."

A diagram of the group of nebulous stars mentioned is given in the above number of *A. N.* One singular thing about these patches of nebulosity is that they each inclose from two to three stars.

I think the supposed connection of M8 with the group of nebulous stars by the nebulous wisp is real but the wisp becomes so faint just before it reaches the nebulosities that the actual connection is not positive. In the enlargement this faint connecting wisp is diffused and lost, though it is easily seen on the original.

In the present picture, the trifid nebula, which is the smaller and

PLATE XXXV*a*.

N

S

PHOTOGRAPH OF THE TRIFID NEBULA AND M 8.

1894, July 3, $9^h\ 20^m$ — $13^h\ 20^m$, Willard 6-inch portrait lens of the Lick Observatory.

PLATE XXXVII. THE ASTROLABE. PLATE XXXVI.

FRONT VIEW. ASTRONOMY AND ASTRO-PHYSICS, No. 130. BACK VIEW.

XUM

XUM

northern of the two, is very well shown and the various dark lanes that ramify it are conspicuous.

The enlargement is about 3½ times and the scale about 1 inch = 0°.5.

MT. HAMILTON, 1894, Oct. 20.

THE ASTROLABE.*

A SUMMARY.

MARGARET L. HUGGINS, LONDON, ENGLAND.

"I nam but a . . . compilatour of the labour of olde Astrologiens. . .
I prey meekly every discret persone that redeth . . . this litel tretis to have my rewde endyting for excused. . . .
—CHAUCER [*Treatise on the Astrolabe, Prologus*].

It would be difficult to say anything new at the present time about the Astrolabe: but it is by no means only what is new that is worth saying.

Much interesting and ever precious intellectual treasure is continually being lost through forgetfulness, and becomes in a sense again new if faithfully set forth once more.

We live it is true in the present, and in it we have to act: but the present is the child of the past, and intimate knowledge of its achievements and failures not only makes clearer our perception of the continuity of human effort and the progressive advance of humanity, but may often guide us with many a hint good for the present,—good for the future. *Experientia docet*: the past is concentrated experience.

The idea of this paper is quite unambitious. A perfect and very charming Astrolabe having been given to Dr. Huggins and myself, I have been led to consider the Astrolabe more closely than I had hitherto done; to look into its literature of "oldè bokis;" and to examine many Astrolabes. I have found the subject so fascinating that it seemed to me a short paper summarizing the leading historical and structural particulars relating to the instrument might be useful as well as interesting. The Summary is the outcome of study of my own; but I frankly own that I have worked into it whatever struck me in my reading as of value for my purpose. Let not anyone feel robbed! Let all, dead or living, from whom I have borrowed, be wise and call my procedure "convey-

* Communicated by the author.

ing,"—conveying, to the end that there may be, as old Sir Thomas Browne hath it,—"no monopoly but a community in learning."

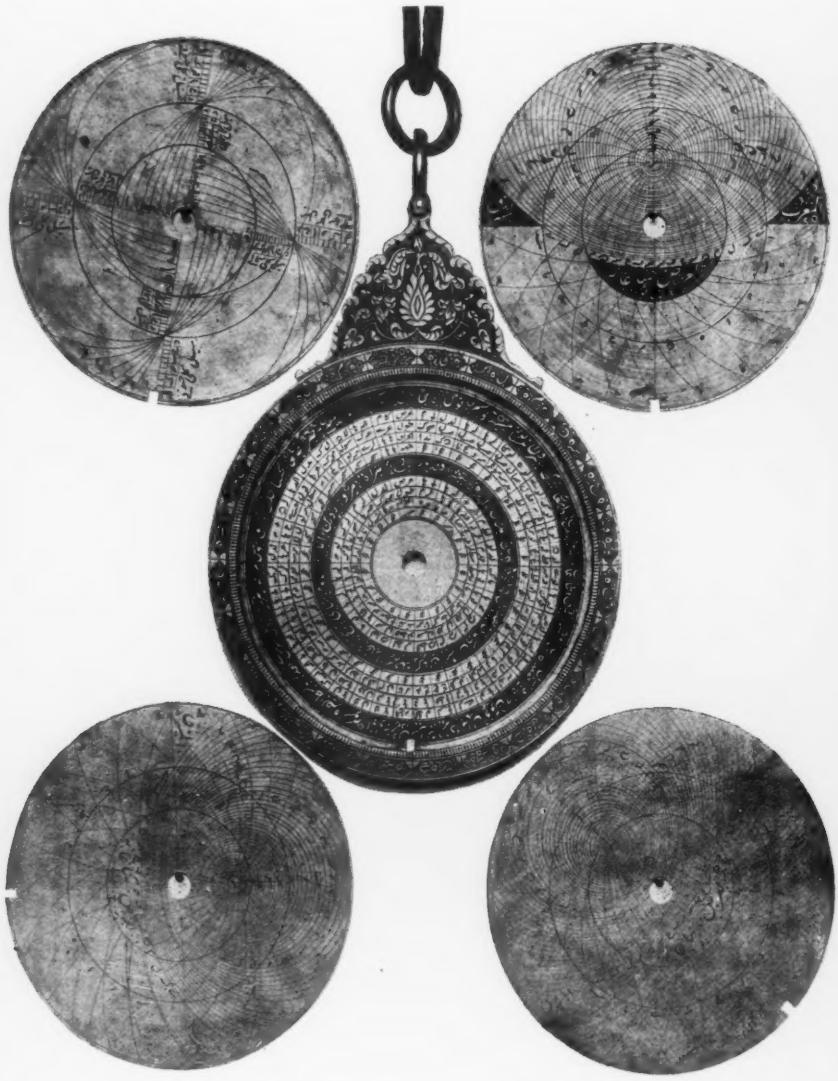
In illustrating the structure of the Astrolabe I have used our own instrument, partly on account of its beauty and perfection; partly because it is of a very usual size. Plates XXXVI, XXXVII and XXXVIII represent its back, front and four interior tables or plates. It is made for about latitude 32° N. In diameter it measures just 5 inches, while it has a length of a little over 8. It is ⅜-inch thick, and weighs 2 lbs. 2 oz. The material is brass, the work is Persian inscribed in Arabic, and it dates probably from the beginning of the 18th century. The engraving on it is excellent and the ornament introduced is skillfully relieved with slight retroussé work. It is very similar indeed in design and in workmanship on a small scale, to the splendid Astrolabe of Shah Husain, King of Persia, now in the British Museum, which was made A. D. 1712 (A. H. 1124) and which is not merely the only "complete" (Támm) Astrolabe known, but is also probably the most beautiful one existing.

The usual material for Astrolabes was brass: but sometimes they were of gilded copper, or of hard wood; and sometimes silver inlaying was used. The size varied much. The largest I have seen is one in the British Museum made in London at the end of the 13th century having a diameter of about 18 inches. The next largest I have seen is the one of Shah Husain already referred to, the diameter of which is 16 inches. There were many made of 7 or 9 inches diameter: some much smaller, of 3 or 3½ inches. None I believe have had a diameter less than 2 inches. Upon the whole the oriental ones are the most beautiful; but many European ones are also ornamented; while some oriental ones are very plain.

The student of aesthetics indeed finds much to delight him in the study of Astrolabes. The singular suitability of the instrument for artistic treatment seems to have inspired more or less every maker,—even in times when most instruments were touched with beauty,—and it is rarely that one meets with a specimen without some peculiar charm. The two parts upon which artistic invention and skill were chiefly lavished were the *Kursi* and the *Rete* (see Plates XXXIX and XXXVI). But the subsidiary parts are often very interesting, and in some French Astrolabes the zodiacal signs are given in animal and human forms which are exceedingly effective. Oriental characters lend themselves of course admirably to artistic effect, and in oriental Astrolabes texts from the Koran are often (surely most suitably) introduced.

XUM

PLATE XXXVIII.



THE ASTROLABE: INTERIOR TABLES AND PLATES.

XUM

UM

XUM

Astrolabes are of two kinds, spherical and planispheric. This paper deals only with the latter to which the term Astrolabe in the 16th and 17th centuries was practically, exclusively applied. The general appearance and structure of the instrument will be understood from an examination of Plate XXXVI, (face) Plate XXXVII, (back) Plate XXXIX (index). It consists essentially of a single piece of some weight with a hollow on the *face side* into which fitted certain *Tables* or *Plates*, and an upper piece called the *Rete*. The weight of the Astrolabe saved the use of a plumb-line. Plate XXXIX gives an index to the particular parts. The *Rete*, which formed the face of the instrument (see Plate XXXIX), had the names of certain stars on its pointers or projecting pieces, and the *tip* of each projection was understood to give the star's centre. The *Rete* rotated, and the almacantars and azimuths of a table placed underneath it can be seen through the reticulations for fixing the positions of stars. The inner circle of the *Rete* contained the Zodiacal signs in degrees.

It is not possible in this Summary to go into minute details, but a few notes in addition to those supplied in Plate XXXIX may be acceptable. Movable indices are not found in Eastern Astrolabes, but they occur in various forms in European instruments. The *Label* (Plate XXXIX), when there was also a *Rule*, was used on the face of the instrument. The parallelogram on the back is almost universally present, but in Eastern instruments there are no lines from the corners to the pole. A figure is given in Plate XXXIX of the European *Umbra Recta and Versa* parallelogram. The parallelogram is for measuring heights of terrestrial objects accessible or inaccessible. It is obvious that for altitudes greater than 45° the base lines called *Umbræ rectæ* are used; and the perpendic ular sides, the *Umbræ versæ*, for lesser heights than 45°. These lines are divided into 12 parts, and the terms *Umbræ rectæ* and *Umbræ Versæ* are borrowed from the Arabic. (For details of the method of working the parallelogram, see Chaucer's Treatise, Part II, § 41-43, Skeat's Edition of Chaucer's Works.) The upper quadrant of the central figure in Plate XXXIX contain sines and arcs for various purposes. The arrangement of the back indeed varied much. The scale of degrees on the circumference was of course an invariable feature; and so was a Zodiacal circle. But the other circles in Eastern Astrolabes might have the days of the year;—lunar mansions, etc., while in European instruments there might be circles of the Saint's days and of Sunday letters.

The *Tables*, *Climates*, or *Plates* (see Plates XXXVIII and XL) number, and also in matter. They were always thin and were

varied in used under the *Rete*—the whole series packing into the hollow of the Astrolabe, and the one required for the time being placed uppermost. On some European *Tables*, a map of the World in polar projection was given; but they usually showed projections of the sphere drawn for various latitudes. It was usual to mark the latitude for which each *Table* was constructed, under the horizon obliquus. But even without this it is easy to see at a glance for what latitude a *Table* is drawn by reckoning the degrees from the zenith to the S. point of the equinoctial or equator, or from the pole to the horizon obliquus. The vertical circles or azimuths cross of course the almucantars or latitude circles, and proceed by intervals of 10 degrees; *i. e.*, every 10th azimuth is traced. Astrological *Tables* are found on both Eastern and Western Astrolabes and relate usually to the zodiac and the planets. In Northern Astrolabes, that is those for use in northern latitudes, the tropic of Capricorn is at the border of the *Tables*. In Southern instruments the tropic of Cancer takes this place.

The term *climate* used above, it may be added, means the belt of the Earth included between two fixed parallels of latitude. In Plate XL is shown a *Table* on a small scale drawn for about latitude 52° N. The east and west of the Astrolabe are read as are dexter and sinister in heraldry, the Astrolabe being supposed to be held as is a shield. Astrolabes are classed in the east according to the number of circles or almucanters inscribed on them.

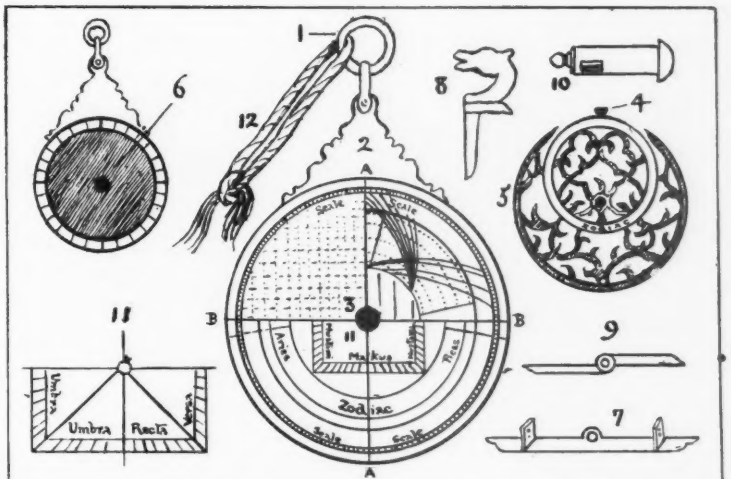
The Tâmm or *Perfect Astrolabe* was inscribed with 90 circles each answering to 1°. (One only is known to exist.)
The *Nisfi* or *Bipartite* with 45 circles each answering to 2°.
The *Thulthi* or *Tripartite*, 30 circles each = 3°.
The *Khumsi* or *Quinquepartite*, 18 circles each = 5°.
The *Sudsi* or *Sexpartite*, 15 circles each = 6°.

Other modes of inscription were quite uncommon.

It is impossible to handle a good Astrolabe without being struck with its comprehensiveness. It combines in itself quadrant, planisphere, theodolite, globe,—and the combination is a marvel of portability and convenience. It is easy to understand Chaucer calling it a "noble instrument:" it is easy to enter into the feeling of Blagrave who spoke of one form of it as a "mathematical jewel." Alas! that the Astrolabe is not capable of higher precision.

History.

"L'invention d'iceluy," says Jacquinot [1545] of the Astrolabe,—"les uns l'ont attribuée à Mesahalach, les autres à Ptolo-



Latin	English	Arabic
1. Armilla suspensoria.	1. Ring.	1. Halkah.
2.	2.	2. Kursi.
3.	3.	3. Mahan.
4.	4. Calculer.	4. Muri
5. Aranea or Volvellum.	5. Rete.	5. 'Ankabút.
6. Mater or Rotula.	6. Mother.	6. Umm.
7. Alidade or Verticulum	7. Rule.	7. 'Izadah.
8. Equus restringens.	8. Wedge.	8. Faras.
9.	9. Label.	9.
10. Axis. Clavus.	10. Pin.	10. Kutb.
11. Scala altimetra or Quadrans.	11. Umbra recta & versa	11. Mustawi & Ma'kús.
12. Tympani.	12. Cord. Tables. Plates.	12. Iláhah. Safáh, plural Safihah.

AA. Linea meridionalis.	= Line of Mid-day or South Line.	= Khatt Nisf-an Nahar.
BB. Horizon rectus.	= Level Line.	= Khatt al-Istiva

Circuli progressionum	= Almicanters.	= Almucantarát. (Bridges).
Circuli verticales.	= Azimuths	= Sumút.

M.L. Huggins, del.

1894

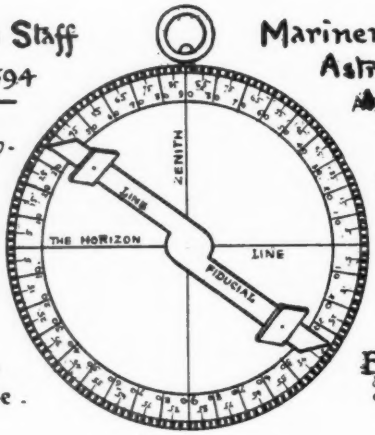
XUM

A Cross Staff A.D 1594

Sketched from Blundeville.

Mariners' Astrolabe. A.D 1594

Sketched from Blundeville



Early Quadrant

Sketched from N. Bion. (The Construction & Uses of Mathematical Instruments)

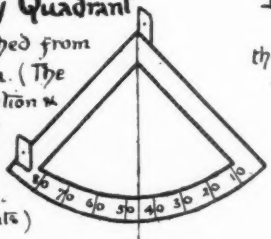
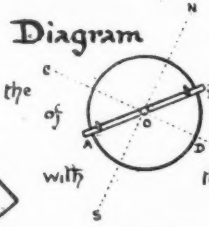
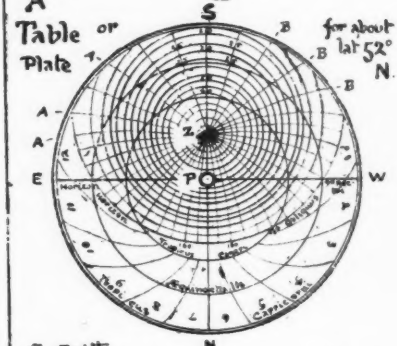


Diagram showing the principle of taking altitude with the Astrolabe.



A Table or Plate for about lat 52° N.



Z. Zenith.
P. Pole
AAA. Almicanters.
BBB. Azimuths.
Horizon rectus = Sensible Horizon
Horizon obliquus = Rational Horizon.
1.2.3 &c = Hours of the Planets
(From Skeat)

From the Bréviaire de Saint Louis: an Illuminated MS. of the XIII cent. (Bibliothèque d'Arsenal. Paris.)

Sketched from "Science & Lettres au Moyen Age" par Paul Lacroix

H.E. Huggins: fecit. 1894

mée, combien que longtemps auparavant avoit esté inventé d'Abraham on d'un nommé Lab, dont quelques-uns ont voulu dériver ce nom Astrolabe, comme du premier auteur."

It is amusing to read the old Frenchman's words: but even now there is no certainty as to the inventor of the Astrolabe. Ptolemy who may have got his ideas about it very probably from Hipparchus, describes a planisphere in the 8th book of the Almagest, and the planispheric Astrolabe of the Arabs is a modification of Ptolemy's planisphere; but the precise date of the first Astrolabe such as we are now considering, cannot be ascertained. It certainly, however, originated in the East, and was early used in India, Persia and Arabia. It became known in Europe by its introduction into Spain by the Arabs, and as the Arabian astronomers had excellent Astrolabes in the dark ages there is good reason for believing the instrument to be much older. The perfection of Arabic astronomical instruments about A. D. 700 was very great indeed.

We have evidence in various illuminated MSS of the astronomical use of the Astrolabe in Europe in the 13th century. A figure from one of these is reproduced on Plate XL which is of considerable interest, for not only is an Astrolabe shown in use, but the observer is represented with one of those *view-tubes* which have often—but erroneously—been taken for early telescopes. By the 14th century the Astrolabe was in general use in Europe; in the 16th and 17th centuries its use was universal. There were different forms of the instrument; but we know which one was most popular in the 16th century for Blundevile, writing in 1594, speaks thus of the Astrolabe of *Stöffler*,—"which for these hundred yeares or thereabouts, hath beene had in most price and estimation, as an instrument containing all the uses, or at least the most part of all other Mathematicall Instruments." The Astrolabe was only completely superseded at the beginning of the 18th century. The invention of Hadley's quadrant in 1731 gave it its death blow in Europe.

Europe adopted the Arabian Astrolabe. Indeed Astrolabes actually Arabian were common in Europe as late as the end of the 16th century. This is proved by the fact that E. Danti [1578] gives Arabic as well as Latin names in his tables of the fixed stars for the convenience of those who employed Arabian instruments. European makers, however, seem only to have produced Northern Astrolabes, and they very frequently added the piece known as the Label which is not found in oriental instruments. The derivation of the word Astrolabe from ἄστρον and λαβη is obvious.

XUM

In the East the instrument is almost universally named the Usturláb.

The Astrolabe is essentially the same wherever its use has obtained. It only varies. One European variation is, however, of so much historical interest that it deserves a word of notice.

The spirit of maritime discovery stirred men mightily in the 15th century; but long ocean voyages called imperatively for improved instruments of navigation and especially for one for finding latitude easily. A rude quadrant has been used by Diego Gomez for this purpose, but the adaptation of the astronomer's Astrolabe to mariners' use by Martin Behaim in 1480 was a distinct and important advance and one which Columbus keenly appreciated. It was the complement of the advance made towards the determination of latitude by the first publication of tables of the Sun's declination in 1475 by Regiomontanus in his *Calendarium Novum*. The mariner's Astrolabe of Behaim was some 8 or 9 inches in diameter and of some thickness. A figure of such an instrument taken from Blundevile's work [1594] is given in Plate XL. A cross-staff of the same period and from the same work is also given.

The history of the Astrolabe is closely connected with that of Astrology. Nor is this surprising, considering the necessity astrologers were under of constantly observing the heavenly bodies in the practice of their calling. The handiness and comprehensiveness of the instrument could not fail to commend it to so shrewd a class of men. In the West astrology has practically disappeared. It has no basis that will bear scientific investigation. But it is well to remember that the requirements of judicial astrology led to the production of a great number of useful tables and observations. It is a fact worth noting that the first lunar tables constructed on the Newtonian Theory were intended for use in the calculation of nativities.

In the East—their birth quarter—both astrology and the Astrolabe still flourish. How amazingly they did flourish may be gathered from the statement of Marco Polo that in the city of Cambaluc alone, there were 5000 astrologers and soothsayers; and he mentions the Astrolabe as in use among them.

The amusing use of the Astrolabe described in the 161st night of the Arabian Nights is worth quoting once again because so typical of Eastern custom.

A young tailor had fallen desperately in love with the daughter of the Kádee of Bagdad and was looking forward with feverish impatience to visiting her. Naturally wishing to make the most

favorable impression he decided to shave and go to the bath beforehand. So he sent for a barber, who instead of proceeding to the shaving, after an exasperating amount of talk, "took out a handkerchief and opened it; and lo, there was in it an Astrolabe consisting of seven plates; and he took it and went into the middle of the court where he raised his head towards the Sun, and looked for a considerable time; after which he said to me (the tailor), "Know that there have passed of this our day,—which is Friday, and which is the tenth of Safar, of the year 263 of the flight of the Prophet,—upon whom be the most excellent of blessings and peace!—and the ascendant star of which according to the required rules of the science of computation, is the planet Mars,—seven degrees and six minutes; and it happeneth that Mercury hath come in conjunction with that planet; and this indicateth that the shaving of the hair is now a most excellent operation." (Arabian Nights, Lane's Trans., Vol. I, p. 331-2).

In the East of to-day as has been remarked the Astrolabe is frequently used. One use to which it is put by Mohammadans is to find the exact position of Mecca as regards the place of the observer. It may be remarked that Lane mentions (Arabian Nights, Vol. I, p. 384, note 57) that the Arabs sometimes use a plumb-line quadrant instead of the Astrolabe. Such an instrument would be essentially that figured in Plate XL, though there was much variety in the details of such quadrants. Many had rings for suspension; and many were solid, and engraved with considerable complexity.

To English speaking people it is of great interest that their classic Geoffrey Chaucer,—the Father of English poetry—wrote *A Treatise on the Astrolabe*. Of Astrolabes in Europe, I think it well to mention the following:

Two at Merton College, Oxford.

One at King's College Library, Cambridge.

Several at the S. Kensington Museum in the Oriental collections.

Twenty-eight at the British Museum. This collection, which is of great interest, includes the superb Shah Husan instrument. It is inscribed in Arabic. It is not fully perfect as it wants Rule, Horse, Fals and Cord.

Ten or eleven, some of them belonging to learned societies, are described by Mr. Morley in his work on the Astrolabe.

Eight were in the Spitzer collection of antiquities recently sold in Paris, and may be studied to some extent in the fine illustrated

catalogues published of the collection.

Eleven (some very good specimens) were sold in London at Puttock and Simson's this spring.

One belongs to Mr. Knobel, F. R. A. S. This is perfect in all its parts, engraved in Kufic character, and is of the 13th century.

One is in the library at Nuremberg. This Astrolabe belonged to Regiomontanus.

One in the Bibliothéque Nationale, Paris. This was made A. D. 905 and is the earliest Eastern Astrolabe known to us I believe.

One in a private collection in France, mentioned by Morley.

USE.

The principle upon which the use of the Astrolabe for altitude taking rests is obvious. Let the circle in the diagram (Plate XL) be considered as a solid flat fixed in one position with Rule attached to its centre round which it is free to move. If a horizon line CD drawn upon the circle points towards a point Q in the heavens in the plane of the circle, it is obvious that by turning the Rule AB towards any object P in the plane of the circle the angle BOB will be the angle subtended by P and Q at the eye or their angular distance on a globe, and this angle may be measured if the circumference of the circle be graduated: Thus if the plane of the circle pass through the poles N and S, and CD point towards the equator, then when the Rule points towards P, NOB, its N polar distance, or BOD, its declination, may be measured.

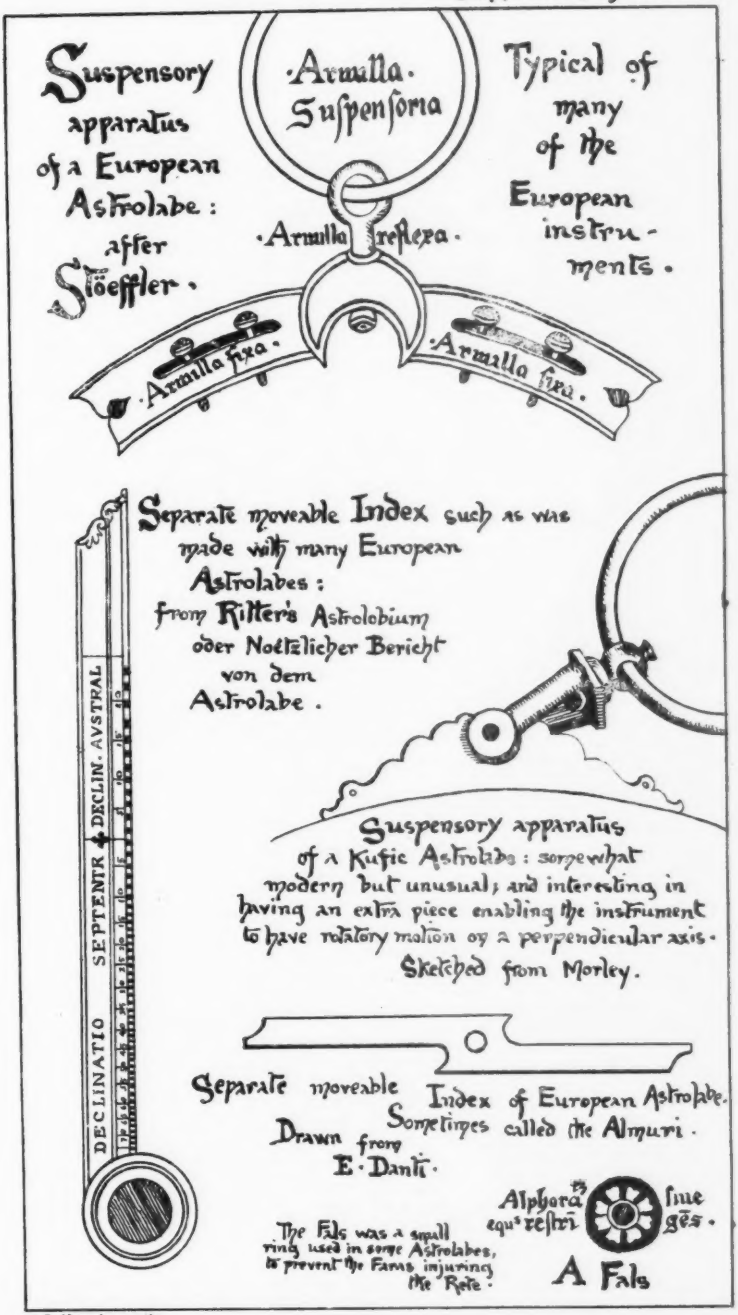
The mode of using the Astrolabe recommended by Chaucer is as follows:

"Put the ring of thyn Astrolabie up-on thy right thoumbe and turne thy left syde agayn the light of the sonne. And remeve thy rewle up and doun, till that the stremes of the sonne shyne thorgh bothe holes of thy rewle. Loke thanne how many degress thy rewle is areised fro the litel crois (east point) up-on thy est, and tak ther the altitude of thy sonne."

When the Astrolabe was to be used at sea "the observer was instructed to sit down and place himself with his back to the mainmast, hold the Astrolabe by the ring, hanging on the 2d finger of the left hand and move the *alidada* or *Label* up and down with the right until the Sun was on with both sights." (Markham).

The Sun was never observed directly through the sights. The stars were. In the better Astrolabes there were two pair of holes

Supplementary Plate.


Suspensory apparatus of a European Astrolabe: after Stöeffler.
·Armilla· Suspensoria
·Armilla reflexa·
Typical of many of the European instruments.
·Armilla fixa·
·Armilla fixa·
Separate moveable Index such as was made with many European Astrolabes: from Ryff's Astrolabium oder Noetzlicher Bericht von dem Astrolabe.
DECLINATIO SEPTENTR ✦ DECLIN. AVSTRAL
Suspensory apparatus of a Kufic Astrolabe: somewhat modern but unusual; and interesting in having an extra piece enabling the instrument to have rotatory motion on a perpendicular axis. Sketched from Morley.
Separate moveable Index of European Astrolabe. Sometimes called the Almuri. Drawn from E. Danti.
Alphora equi restri sive geſs.
A Fals
The Fals was a small ring used in some Astrolabes, to prevent the Farms injuring the Rete.
M·L·Huggins·fecit·

XUM

in the sights; a very small pair for solar observations; a larger pair for stellar ones.

Briefly, the Astrolabe was used for taking observations of the Sun, Moon and stars; for determining latitude; for determining approximately the points of the compass; for determinations of time; for measuring heights of mountains, buildings, and distances generally; for construction of horoscopes, and for many other operations connected with judicial astrology. In the East, as has been stated, one of its very important uses was, and is, to find the exact position of Mecca as regards the place of the observer.

Bibliography.

The best catalogue of works on the Astrolabe with which I am acquainted is that forming part of the *Bibliographie Générale de l'Astronomie* by *J. C. Houzeau* and *A. Lancaster*, pp. 630-649.

It appears to me that the most useful works on the whole to consult, are the following:

G. Chaucer, [1391] *Treatise on the Astrolabe.*—Edition by W. W. Skeat in his edition of the Complete Works of Chaucer. Skeat's introduction, notes and illustrations to the treatise are all of the utmost value. A small book on Chaucer's Treatise by A. E. Brae is of interest.

J. J. Stöffler, [1512] *Elucidatio Fabrice ususque Astrolabii, etc.*—This work is very full and complete and has many excellent illustrations. It is, too, a beautiful book as regards printing, etc. There is a French translation of Stöffler's book by J. P. de Mesmes (published 1556). This work contains the text of Stöffler and the most necessary illustrations.

M. Blundevile, [1594] *His Exercises.*—Interesting and useful, and has good plates.

F. Ritter, [1599] *Astrolabium das ist, etc.*—Useful. Excellent plates.

W. H. Morley, [1856] *Description of a Planispheric Astrolabe constructed for Shah Husain, King of Persia.*—This work is much more than an admirable and exhaustive monograph on Shah Husain's Astrolabe. It contains besides an excellent account of Astrolabes generally, and has many useful notes. It is an invaluable work. The plates give Shah Husain's Astrolabe full size. This unfortunately makes the book awkward and unwieldy to use, but this is its only fault.

An account of the Astrolabe based on oriental information will be found in the *Voyages du Chev. Chardin en Perse* [1811] Tome IV, p. 335 *et seq.*

Among minor works may be mentioned an article in the *English Encyclopœdia*, unsigned, but which I venture to think must have been written by the late Professor De Morgan.

Columbus by Clements Markham contains a little respecting the Mariner's Astrolabe.

ON THE QUADRUPLE STAR ζ CANCRI.

PROFESSOR SEELIGER.

The results of numerical computations of the kind which I have published in my two papers upon ζ Cancri*, bear more or less the character of interpolation formulæ. It is not possible to determine their constants with so great exactness that a completely satisfactory accordance with the observations of future years can be guaranteed. This fact I have expressly insisted upon, especially in II.

On this account it is on the one hand not surprising if the places deduced from theory depart slightly from the observations after a time, and on the other hand, it is useless to make continuous readjustments of the theory at short intervals, for the purpose of reconciling it with the observations, if the characteristics of the latter results are already found in the earlier.

At the time of the discussion in I, observations up to the year 1880 were at my disposal, while in II, measures to 1888, though, it is true, partly in insufficient number, could be used.

The warrant for the second research, therefore, lay not so much in the increased observational matter as in the circumstance, that I could then more fully and thoroughly develop the theory in several directions, and considered that by this discussion, I could arrive at a certain conclusion.

I cannot therefore look upon the appearance of new observations as a challenge to a present renewal of my discussion of ζ Cancri.

On the other hand, there have appeared, of late years, attacks by Mr. Burnham, a meritorious double-star observer, upon my theory of the motion of the distant star C, which are calculated to obscure the subject in the eyes of those not well acquainted with my papers.

The arguments advanced with great confidence by Mr. Burnham are indeed calculated only to show that their author neither possesses sufficient knowledge of the subject nor has given himself the trouble to thoroughly examine my papers. On this score I could be content to leave the proper characteriza-

* *Untersuchungen uber die Bewegungsverhaltnisse in dem dreifachen Sternsystem ζ Cancri. Denkschriften der Wiener Akademie 1881.*

Fortgesetzte Untersuchungen uber das mehrfache Sternsystem ζ Cancri. Abhandlungen der k. bayer. Akademie 1888.

In the following pages the first will be designated by I, the second by II.

tion of Mr. Burnham's assertions to the future and to others. On the other hand, I cannot consent to allow the results of my labors to be brought into question through entirely unfounded assertions, and therefore I have brought out in the following pages certain computations, which I consider should be sufficient to put the case in a full light in the eyes of all.

In the following pages I will concern myself singly and alone with the motion of the distant companion C, about the centre of gravity of the two inner stars A and B. Special researches in I and II have arrived at the result, that the observations show no noticeable difference between the centre of gravity of A and B, and the middle point between the two stars, $\frac{AB}{2}$. Furthermore, undulations show themselves in the observations of C, in a manner completely accordant both in position-angle and in distance, which show the position-angle to oscillate about $\pm 2°$, and the distances about $\pm 0''.2$, about a mean value. The constant period of oscillation amounts to very nearly 18 years, and it has been possible to prove the same by more than three full revolutions. The entire phenomenon is fully explained on the assumption that the star C has a near dark companion.

The yearly means from 1880 forward, discussed in II, were not sufficient for a complete confirmation, which is now made possible by the publication of several valuable series of observations. From the year 1888 forward, however, the establishment of reliable yearly means would have been to a certain extent impossible, had not Messrs. Schiaparelli, H. Struve, and Lovett had the great kindness to communicate to me the desired extracts from their records. Especially do the very numerous and excellent measures of Schiaparelli form an essential support of the following remarks. It was thus possible to adduce 15 new and certain yearly means, from 1880 to 1894. After the above remarks, there can be no question of connecting these new results with the earlier computations. On the contrary, I consider that such attacks as those of Mr. Burnham can best be met by treating the newer measures, which have almost no personal connection at all with those made in the forties or fifties, entirely by themselves. After I have made it apparent that my earlier formulas accord with the new observations as closely as can at all be expected, I shall show that the newer measures also, considered by themselves, in turn fully satisfy the assumption of a dark companion to C, corresponding, in fact, quantitatively, to the earlier formulas, and that without such an assumption, residual errors

remain which no one, certainly, will seriously attempt to explain by the accumulation of personal errors.

I now proceed to give the annual means of the observations of C, referred to the middle point of A and B. The names of the observers, Hall, Sr., Jedrzejewicz, Schiaparelli, and Hermann Struve, will be designated by the abbreviations, H., J., Sp., HΣ.

1800 +	Observer.	Wt.	p	ρ	Mean.
			°	″	
80.16	Franz.	2	130.60	5.545	
80.21	H.	4	132.45	5.465	1880.21 (11.10) 132°.25 5″.372
80.22	J.	4	132.50	5.193	
80.31	Seabroke	1	133.72	—	
81.24	J.	4	131.29	5.467	
81.25	Doberck.	2	131.75	5.400	
81.26	Seabr.	1	131.37	—	1881.28 (17.16) 131°.42 5″.431
81.28	O. Σ.	2	130.80	5.210	
81.30	Sp.	4	131.57	5.445	
81.30	H.	4	131.54	5.508	
82.20	H.	4	132.03	5.587	
82.25	Seabr.	2	129.83	—	1882.24 (14.13) 131°.13 5″.517
82.26	Sp.	4	131.06	5.468	
82.27	J.	4	130.94	5.497	
83.13	Engelm.	4	129.43	5.653	
83.29	Sp.	4	130.16	5.598	
83.31	H.	4	130.21	5.567	1883.26 (15.14) 129°.73 5″.599
83.32	Seabr.	1	128.33	—	
83.35	Küstner.	2	129.20	5.557	
84.21	Perrotin.	2	128.95	5.561	
84.25	Sp.	4	129.21	5.589	
84.26	O. Σ.	4	129.22	5.418	
84.28	H.	4	126.59	5.625	1884.28 (17.14) 128°.63 5″.546
84.38	Seabr.	1	131.00	—	
34.39	Smith.	2	128.90	—	
85.28	Seabr.	1	126.20	5.760	
85.29	Engelm.	4	128.18	5.654	1885.29 (9) 128°.09 5″.643
85.29	Sp.	4	128.48	5.603	
86.04	Tarrent.	2	125.71	5.480	
86.24	Seabr.	1	126.40	(5.06)	
86.25	Smith	1	127.30	(4.61)	
86.28	H.	4	126.26	5.600	1886.26 (20.14) 126°.99 5″.591
86.29	J.	4	126.98	—	
86.30	Engelm.	4	128.58	5.569	
86.30	H. Σ.	4	126.84	5.660	
87.24	Sp.	4	125.18	5.598	
87.24	H.	4	126.96	5.595	
87.30	H. Σ.	4	126.17	5.600	1887.27 (14.12) 125°.96 5″.598
87.35	Seabr.	1	125.40	(4.51)	
87.36	Smith.	1	124.80	(4.64)	

1800 +	Observer.	Wt.	p	ρ	Mean.
88.25	H.	4	124.13	5.520	
88.27	Sp.	4	124.31	5.684	
88.28	Smith.	2	125.20	(4.65)	1888.29 (17.15) 124°.27 5″.625
88.33	O. Σ.	2	123.84	5.667	
88.33	H. Σ.	4	124.01	5.610	
88.36	Maw.	1	124.70	5.790	
89.12	Seabr.	1	125.30	(4.85)	
89.18	Highton.	1	124.60	5.310	
89.19	Leavenworth	2	123.80	5.530	
89.22	Sp.	4	123.01	5.536	1889.22 (18.17) 123°.79 5″.534
89.23	H. Σ.	4	123.51	5.590	
89.23	H.	4	123.91	5.680	
89.29	Maw.	2	124.50	5.240	
90.23	Sp.	4	123.43	5.514	
90.24	Comstock.	1	124.80	5.470	1890.28 (13) 123°.51 5″.507
90.28	H.	4	123.51	5.432	
90.33	H. Σ.	4	123.26	5.580	
91.21	Sp.	4	122.43	5.527	
91.22	H.	4	122.87	5.479	
91.26	Maw.	2	122.50	5.300	1891.26 (13) 122°.76 5″.490
91.27	H. Σ.	2	122.31	5.570	
91.65	Byers & Collins	1	125.10	5.610	
92.26	Sp.	4	122.40	5.443	1892.26 (4) 122°.40 5″.443
93.16	Jones	1	(115.70)	5.320	
93.21	Lewis	2	123.70	5.185	1893.24 (6.7) 122°.54 5″.288
93.25	Sp.	4	121.96	5.331	
94.16	H. Σ.	4	122.39	5.430	
94.16	Lovett.	2	123.10	5.540	1894.19 (10) 122°.46 5″.405
94.24	Sp.	4	122.22	5.313	

On this collection I would remark as follows:

1. The assignment of weights has been made according to the scheme set forth in II. This is at any rate sufficient for the purpose proposed, although, by its use the new observations, made with such superior means, are certainly assigned too small a weight.

In a definitive discussion, the yearly means of Schiaparelli, made from very numerous and apparently very accurate nightly means, should be assigned a greater weight. The yearly means of Schiaparelli are, according to the series, formed from 13, 12, 14, 8, 10, 10, 14, 14 evenings' work.

2. The reduction of the measurements taken from A or B to C, to $\frac{A+B}{2}$ has been carried out with the aid of assumptions as to the relative positions of A and B, which are not entirely certain, and could not be exactly determined without more considerable

computations. This inexactness, which besides is scarcely perceptible, can only affect the last places in the observations of HΣ, in the above figures.

3. With regard to the constant personal errors, the following corrections were obtained by comparison with the ephemeris given in II, p. 71.

Sp.	− 0°.85	+ 0″.074
H	+ 0 .51	− 0 .025
HΣ	− 0 .41	+ 0 .097

The last observation of HΣ seems, however, to contradict this correction. It is separated from the earlier ones by a three years' interval, and is derived from 6 comparisons of C with A and B, which give entirely accordant mean values. It therefore seems better to leave this last measure of HΣ uncorrected. Besides, it appears pretty plainly at the first glance, that on this account the last yearly mean is uncertain as to distance, and this will be found confirmed as we proceed.

4. The measures of OΣ from the year 1881, and those made with the 30-inch refractor, are taken directly without correction from the appendix to II.

The grounds for this proceeding I leave unexplained, as it cannot have a perceptible effect on the results. All other observations are, as before, left uncorrected.

As respects the constant personal errors applied in II, and in the continuation of it in the present notice, they make no pretence at being anything more than the mean of the departures from the ephemeris, which in its turn is deduced from provisorily corrected observations. On this account the observations appear to be referred to a more or less arbitrary system of position-angles and distances.

The corrections found, however, may be regarded as actual personal equations, if the mean of all the applied corrections does not differ noticeably from zero, otherwise the adopted system is not the normal one.

The corrections employed in II and the present paper, if where different corrections have been found for the same observer, the simple means are used (with the exception of Sp., in whose case, on account of the great disparity in the instrument, this is hardly allowable), are then,

	°	″
W. Σ.	+ 1.82	−[0.070
O. Σ.	− 0.47	−.0.125
D.	+ 0.84	− 0.033
S	+ 0.02	− 0.003
Δ	− 0.26	− 0.031
Mädler	+ 0.30	—

	°	″
Du.	− 1.56	− 0.050
Sp. 1	+ 1.04	+ 0.004
Engelmann	+ 1.38	+ 0.217
J.	+ 0.71	− 0.103
Kaiser	+ 1.79	− 0.280
Sp. II.	− 0.85	+ 0.074
H.	+ 0.51	− 0.025
H. Σ.	− 0.41	+ 0.097
Mean	+ 0.35	− 0.024

If we take the most certainly determined corrections, namely, WΣ., Δ, Sp_I, Sp_{II}, H, HΣ, we get the mean value + 0°.31 + 0″.008. According to this the system should give position-angles somewhat too great, while the distances correspond very nearly to the truth. As, however, a constant correction to the angle has no influence on the theory, the selected system must be regarded as nearly normal. Besides, this positive correction is due principally to the unusually large correction to WΣ.

In any case, there is no apparent ground for doubt that my researches in II are based upon observations which have been referred to an essentially correct system, although the possibility is not excluded that in the future, when it is to be hoped that many of the large telescopes which now stand prepared for the work will be employed on the measures of ζ Cancri, a modification may be made in the one or the other direction.

The above quoted annual means were next, to facilitate comparison, reduced to the same tenth of their respective years. Attention should, however, again be called to the circumstance, that the last places, to the hundredths of degrees in position-angle, and the thousandths of seconds in distance, are uncertain to a few units; this results from the manner in which they have been computed. To the fifteen newly deduced yearly means I have prefixed the four next preceding from II. I am not in a position to undertake any alteration or completion of these.

To begin with, the observed position-angles and distances, p_B, and ρ_B, should be compared with the values resulting from the theory, p_R and ρ_R.

The differences observed—computed are found in the collection given below, in the column O—C. A merely passing glance at these figures shows that on the whole the accordance with the theory is satisfactory.

The peculiar undulations, at any rate, which the observations show in p and ρ have almost entirely disappeared. Outstanding differences remain, of a systematic character indeed, but which

for the objective critic, have no longer any striking significance, since systematic errors are to be expected in the observations, and besides, it is a question of an extrapolation of some ten years. In consideration of this, the accordance between theory and observation must be called satisfactory.

The sums of the absolute differences amount in position-angle to 8°.56, in distance to 0″.769.

The undulations which the observed p and ρ show, and which, as I have shown in II, follow with almost mathematical regularity a cycle of about 18 years, come out more plainly if we seek to represent them by a circular motion. It is well to note here that the whole matter is a question of a progressive change of only about 9° in position-angle. If we take this progressive change of p according to II, and make the equation

$$p_0 = 145°.46 - 0°.513\ (t - 1850.2),\ \rho_0 = 5''.459$$

expressing the simple mean value of all ρ_B, found without regard to weight, the differences $p_0 - p_B$, $\rho_0 - \rho_B$, are very nearly what was above regarded as the outstanding errors of the observations if the assumption that the star C is not double, is admitted.

Differences of a similar character have now begun upon their fourth repetition. It is repugnant to me, in view of these figures, to criticise the contention of Mr. Burnham, that such departures should be considered as a remarkable accumulation of personal errors, now occurring in the same order for the fourth time. To criticise the like assertions with a parliamentary expression is scarcely possible.

	p_B	ρ_B	p_R	ρ_R	O—C		p_O	$p_O - p_B$	$\rho_O - \rho_B$
	°	″	°	″	°	″	°	°	″
1876.2	130.51	5.317	130.91	5.281	− 0.40	+ 0.036	132.12	+ 1.61	+ 0.142
77.2	131.15	258	131.21	255	− 0.06	+ 0.003	131.60	+ 0.45	+ 0.201
78.2	131.42	295	131.57	259	− 0.15	+ 0.036	131.09	− 0.33	+ 0.164
79.2	132.62	258	131.86	294	+ 0.76	− 0.036	130.58	− 2.04	+ 0.201
80.2	132.25	372	131.95	351	+ 0.30	+ 0.021	130.06	− 2.19	+ 0.087
81.2	131.46	425	131.76	422	− 0.30	+ 0.003	129.55	− 1.91	+ 0.034
82.2	131.16	514	131.28	494	− 0.12	+ 0.020	129.03	− 2.13	− 0.055
83.2	129.79	597	130.54	561	− 0.75	+ 0.036	128.52	− 1.27	− 0.138
84.2	128.72	543	129.59	615	− 0.87	− 0.072	128.00	− 0.72	− 0.084
85.2	128.19	642	128.49	651	− 0.30	− 0.009	127.49	− 0.70	− 0.183
86.2	127.06	591	127.32	667	− 0.26	− 0.076	126.99	− 0.07	− 0.132
87.2	126.04	598	126.12	665	− 0.08	− 0.067	126.48	+ 0.44	− 0.139
88.2	124.38	627	124.93	642	− 0.55	− 0.015	125.96	+ 1.58	− 0.168
89.2	123.81	535	123.84	601	− 0.03	− 0.066	125.45	+ 1.64	− 0.076
90.2	123.58	511	122.91	554	+ 0.67	− 0.043	124.93	+ 1.35	− 0.052
91.2	122.80	494	122.20	475	+ 0.60	+ 0.019	124.42	+ 1.62	− 0.035
92.2	122.43	447	121.75	403	+ 0.68	+ 0.044	123.90	+ 1.47	+ 0.012
93.2	122.54	290	121.60	335	+ 0.94	− 0.045	123.39	+ 0.85	+ 0.169
94.2	122.46	404	121.72	282	+ 0.74	+ 0.122	122.89	+ 0.43	+ 0.045

In order to present clearly the decisive fact, that the last quoted nineteen yearly means, to which so many and distinguished observers, who do not appear previous to 1876, have contributed (and attention is here called to their extremely close agreement, especially in position-angle) accord with the same period that is deduced in II from the assemblage of the earlier available measures, I have attempted to represent the differences $p_0 - p_B$ by a formula expressing a circular motion with the period named, by the use of the method of least squares.

The result was

$$\text{(II).} \quad p_0 - p_B = -0°.06 + 1°.913 \sin 19°.947t + 0\ .137 \cos 19\ .947t$$

in which the time t is to be expressed in years from 1850.2. If we wish to get a still better approach, we change the variation of p_0 somewhat, so that the equation reads

$$\text{(III).} \quad p_0 - p_B = -0°.06 - 0°.0681 \frac{t}{(10)} + 2°.268 \sin 19°.947t + 0°.286 \cos 19°.947t$$

In the following table the values of position-angles computed from these formulæ are given under II and III, and the outstanding errors are under Δ and Δ_1. The representation attained is a satisfactory one, and indeed, no other was to be looked for. The systematic character of the differences, it is true, can be in part eliminated by a more elaborate theory, possibly the one earlier proposed by myself, and by a discussion carried through with reference to the weights, but for the most part, they are purely personal errors that are here expressed. In my earlier papers I have expressly called attention to this point. The sums of the absolute values of Δ and Δ_1 are from 5°.58 to 6°.05; from this it appears hardly necessary to give the formula III any preference over II.

	$p_0 - p_B$	II	Δ	III	Δ_1	α	Δ_2
	°	°	°	°	°	″	″
1876.2	+ 1.61	+ 0.51	+ 1.10	+ 1.10	+ 0.51	5.493	+ 0.031
77.2	+ 0.45	− 0.15	+ 0.60	+ 0.25	+ 0.20	439	− 0.023
78.2	− 0.33	− 0.49	+ 0.16	− 0.21	− 0.12	465	+ 0.003
79.2	− 2.04	− 1.26	− 0.78	− 1.29	− 0.75	391	− 0.071
80.2	− 2.19	− 1.77	− 0.42	− 1.81	− 0.38	456	− 0.006
81.2	− 1.91	− 1.97	+ 0.06	− 2.08	+ 0.17	449	− 0.013
82.2	− 2.13	− 1.94	− 0.19	− 2.15	+ 0.02	475	+ 0.013
83.2	− 1.27	− 1.69	+ 0.42	− 1.80	+ 0.53	499	+ 0.037
84.2	− 0.72	− 1.24	+ 0.52	− 1.30	+ 0.58	399	− 0.063
85.2	− 0.70	− 0.65	− 0.05	− 0.45	− 0.25	468	+ 0.006
86.2	− 0.07	0	− 0.07	+ 0.07	− 0.14	410	− 0.092
87.2	+ 0.44	+ 0.66	− 0.22	+ 0.77	− 0.33	429	− 0.033

	$p_0 - p_B$	II	Δ	III	Δ_1	α	Δ_2
	°	°	°	°	°	″	″
1888.2	+ 1.58	+ 1.22	+ 0.36	+ 1.35	+ 0.23	490	+ 0.028
89.2	+ 1.64	+ 1.63	+ 0.01	+ 1.73	− 0.09	449	− 0.013
90.2	+ 1.35	+ 1.84	− 0.49	+ 1.87	− 0.52	485	+ 0.023
91.2	+ 1.62	+ 1.82	− 0.20	+ 1.73	− 0.11	534	+ 0.072
92.2	+ 1.47	+ 1.60	− 0.13	+ 1.32	+ 0.15	547	+ 0.085
93.2	+ 0.85	+ 1.12	− 0.22	+ 0.70	+ 0.15	434	− 0.028
94.2	+ 0.43	+ 0.43	0	+ 0.08	+ 0.35	(582)	(+ 0.120)

A not unimportant control, if indeed such is needed, is further afforded by the discussion of the distances. The formula II, if it is assumed that C describes a circular orbit about a dark companion, gives naturally very accordant changes of distance.

If we take a as the radius of the circle which the centre of gravity of C and its companion describes about $\frac{AB}{2}$ we can compute from each ρ_B a value for a. The assembled a, with the differences $\Delta_1 = 5''.462 - a$, where $5''.462$ represents the simple mean, without regard to weights, give an entirely independent confirmation of the theory. If we look at the small residuals, ($\Sigma\Delta_2 = 0''.600$ to $0''.720$) we can not remain in doubt that all the larger periodical undulations in the distances have entirely disappeared.

I have always, in both my earlier papers, looked upon this control as a very important support to the almost demonstrative certainty of the assumption, that C must have a dark companion. I can further only here repeat what I said in II (p. 14) about this assumption: "I for my part do not hesitate to claim for it a certainty so great as is attained by few attempts at explanations in stellar astronomy, which are not at once indicated on inspection."

In conclusion, I must once more, though unwillingly, return to Mr. Burnham. After I had expressly controverted the attacks of this gentleman,† and had shown how peculiar are the ideas he has formed respecting systematic observational errors, Mr. Burnham has seen fit, in No. 120 of the periodical ASTRONOMY AND ASTRO-PHYSICS, not only to reiterate his assertions, but to do this in a tone which I must most decidedly qualify as entirely improper. There is not the least occasion to go into his arguments, since these have been completely refuted in my former papers. I cannot, however, refrain from here reprinting No. III of Burnham's last named notice, since the author's peculiarity herein characterises itself. "It is evident that Professor Seeliger has had little experience in double star work, or he would not have criti-

† *Uber Herrn Burnham's "Invisible Double Stars" und insbesondere uber ε Hydræ. Astronomische Nachrichten, band 132.*

cised my remark that the close pair of ε Hydræ could not possible effect the measures of C. The truth of this statement must be so obvious to every practical astronomer who is accustomed to use the micrometer, that it can hardly be considered a debateable question." I can only express my sincere regret that a practical astronomer should be so surprisingly ignorant of the conditions which must necessarily be considered as indicated by systematic differences, and still more that he should put this ignorance in evidence in so conspicuous a manner.

It naturally follows from this, that no scientific gain can result from any discussion with Mr. Burnham upon the present question. I shall therefore decline to consider any further remarks by this gentleman upon ζ Cancri and my papers, as of no consequence in the case, and shall allow any renewed attacks to remain unanswered.

[Mr. Burnham, at whose request the foregoing article by Professor Seeliger is reprinted in this Journal, desires to state that he finds nothing in this paper with reference to its astronomical assertions or personal peculiarities which calls for, or would justify any reply on his part. For determining the true relations and movements of stellar systems, the micrometer, he thinks, is mightier than the pen.—ED.]

THE GREAT PHOTOGRAPHIC NEBULA OF ORION, ENCIRCLING THE BELT AND THETA NEBULA.*

E. E. BARNARD.

Experiments With a Very Small Lens in Photographing Very Large Nebulæ, etc.

I have recently been experimenting with a small short-focus lens. Some of the results are very interesting.

This lens belongs to a cheap (oil) projecting latern and is 1½ inch in diameter and 3½ inches focus (from the rear lens). It gives a field of about 30°, only one-half of which, however, is at all flat—but on this portion the stars are fairly good. The scale is about 10°.3 to the inch.

The ratio of the aperture to the focal length is 1 : 2.3 while that of the Willard lens is 1 : 5.

This large light ratio makes the lens very suitable for certain

* Communicated by the author.

work where the smallness of the scale is not objectionable—or is really desired,—such for instance as very large diffused nebulosities, large comets, the Milky Way, etc. It will doubtless be also admirably suited for photographing meteors—catching from its great light ratio and large field many meteors that would be entirely missed by such telescopes as the Willard lens.

So far I have made nearly 20 photographs with this lens, which for identification I shall call the "lantern lens."

These exposures range from one second up to four hours.

On account of this light ratio the diffused light of the stars scattered over the sky also photographs, so that very prolonged exposures are only possible with it when the sky is free from milkiness—or whiteness. Its penetrating power is not far from that of our Willard lens.

When the moon is very young, the dark or earthlit portion can be photographed with it in from 1 second to 3 seconds.

The cloud forms of the Milky Way, such as those in the region of M11, are well shown in from 10 to 15 minutes.

An exposure of one hour showed all the great mass of nebulosity near Alpha Cygni, and doubtless 15 or 20 minutes would show it clearly.

One hour showed the full extent of the great Andromeda nebula, and I have no doubt but that it could as well be shown with far less than half that time.

Four hours' exposure was given on the region about the Pleiades. Besides showing the nebulosities of the cluster it showed also the large diffused nebula N. G. C. 1497. This nebula, which was discovered by me with the 6-inch Cooke equatorial of the Vanderbilt University, Nashville, Tenn., on Nov. 3, 1885, was photographed by Dr. Archenhold in October, 1891 (See *A. N.* 3082). I have a fine photograph of it with the Willard lens with three hours' exposure, and of which I shall have more to say in a later paper. The impression with the lantern lens is very strong and does not materially differ (except in point of size) from that with the Willard lens. The nebula is a very singular object, however, and well worth study. It is somewhat over 2° long and seems to be quite complicated in structure.

Probably an exposure of less than half an hour would show this object with the lantern lens. By the way, Dr. Archenhold is wrong in speaking of this object as having been discovered by photography. Visually, on account of its very diffused nature, it is a very faint object in any telescope.

The most interesting, however, of these lantern lens pictures,

XUM

PLATE XLI.

THE GREAT PHOTOGRAPHIC NEBULA IN ORION.

ASTRONOMY AND ASTRO-PHYSICS, No. 130.

XUM

are two of the constellation of Orion (for it takes in nearly the entire constellation).

These were made 1894, Oct. 3 and Oct. 24, with 2 hours', and 1 hour 15 minutes' exposure, respectively.

To my surprise these pictures showed an enormous curved nebulosity encircling the belt and the great nebula, and covering a large portion of the body of the giant. A description of this nebula would not only be complicated but it would fail, also, to give any impression of its form and magnitude; I have, therefore, made the enclosed drawing of it which will show at once its exact location and form. The drawing is on nearly twice the scale of the original negative and the stars are taken from Proctor's Chart.

After I had made this drawing and partly written this paper, I remembered having seen somewhere that Professor W. H. Pickering had once spoken of a great nebula shown on his photographs of Orion and previously unknown. I have looked up his paper on the subject and find it in the *Sidereal Messenger* for January, 1890 (vol. 9, p. 2). I will quote here what Professor Pickering has to say concerning this remarkable object:

"An interesting structure brought out upon our plates is a large spiral nebula whose outer extremity starts in the vicinity of γ Orionis. It passes about four degrees north of ζ, extends to γ thence to β, then north to η, with an outside stream lying nearly north and south, and preceding β about four degrees. Another stream lying nearly east and west precedes η about the same amount. This nebula is about seventeen degrees in length, by nearly the same in breadth, and surrounds a cluster of bright stars including the belt and sword handle, and extending towards γ. The region containing the nebula is noticeably lacking in stars brighter than the eighth magnitude, but contains the very bright stars γ and β. It is possible that a plate with double our present exposures, which we are soon going to try, will fill the space between η and ζ, thus making the great nebula the inner termination of the spiral. This nebula is shown by three different exposures and is very distinctly marked."

Professor Pickering's photographs were made at Wilson's Peak in southern California (altitude 6250 feet) with a Voightländer portrait lens of 2.6 inches aperture and 8.6 inches equivalent focus, with an exposure of three hours. Stars from the 11th to the 12th magnitude were well shown.

In the present pictures the shorter exposure shows the nebula best; this was perhaps due to a darker sky.

XUM

On my drawing, I have marked a portion of the nebulosity, from 1° to 2° east of Tau, with dots, as it is so feeble at this point that I cannot be certain of it. Two other portions, very slightly uncertain, I have also marked with dots; these, however, I am confident exist on the negatives. The rest of the nebula is well shown. It is brightest near 56 and 60 Orionis. Its extreme diameter is about 14° or 15°. Compared with this enormous nebula the old θ, or so-called "great nebula," is but a pigmy.

That this object shown on my plates is the same photographed by Professor Pickering in 1889 there is no doubt, as will readily be seen upon comparing his description with my drawing. The present photographs therefore, fully confirm the pictures of 1889. This confimation is all the more valuable as it was unconsciously and independently made.

MT. HAMILTON, 1894, Oct. 27.

MARS.

PERCIVAL LOWELL.

SEASONAL CHANGES ON THE PLANET'S SURFACE.

That seasonal changes take place upon the surface of Mars, changes of sufficient magnitude to be visible from the Earth, and due directly to the changing seasons of the Martian year, I have recorded in previous papers. In view, however, of the importance of the subject and of the fact that each fresh presentation has added to the evidence of this it seems to me well to embody the matter in a paper by itself, supported by drawings made at different dates and placed for comparison side by side. In these I have reproduced as nearly as possible the values of the markings on the planet on an absolute scale, so that the various parts of the different drawings are all comparable.

For the substantiation of changes on the surface of Mars it is of par-amount importance that the drawings to be compared should all have been made by the same person at the same telescope uuder as nearly as possible the same atmospheric conditions,—since otherwise the subjectivity of the observer, the objectivity of his instrument and the special atmosphere in which he works play so large a part in the result as to mask that trifling factor in the case, any change in the planet itself. How easily this masking is accomplished appears from drawings by different observers of

the same Martian feature at practically the same instant of time. Several interesting specimens of such personal peculiarities may be seen by the curious in Flammarion's admirable thesaurus "*La Planète Mars.*" In some of these drawings purporting to be likenesses of the planet it is pretty certain that Mars would never recognize himself.

To have drawings swear at one another thus across the page is, in the interests of deduction, objectionable. If Mars is to be many, his draughts—man must be one. So much, at least, is fulfilled by the drawings presented with this paper. For they were all made by me at the same instrument under the same general atmospheric conditions as the same personality enters all, it stands, as between themselves, eliminated from all to increased certainty of deduction. Even the different eye-pieces used vary chiefly in a manner to minimize, if anything, and so emphasize the differences observed. For with increasing image the higher power used tends to decrease the contrast. The result is that it largely offsets the difference in contrast due to nearer approach and leaves simply a case of magnification, with the values untouched.

Since, furthermore, the drawings were all make in the months preceding and following one opposition, secular changes are practically out of the question; any changes that appear starting with the presumption of a seasonal character. They constitute of themselves a kinematical as opposed to a statical study of the planet's surface.

The resulting phenomena are, as will be seen from the drawings, much more evident than might be supposed. Indeed they are quite unmistakable. As for their importance it need only be said that deduction from them furnishes, in the first place, strong inference that Mars is a very living world subject to an annual cycle of surface growth, activity, and decay; showing in the second place that this Martian yearly round of life must differ in certain interesting particulars from that which forms our terrestrial experience.

The phenomena evidently make part of a definite chain of changes of annual development. So consequent and, in their broad characteristics, apparently so regular are these changes that I have been able to find corroboration of what appears to be their general scheme in drawings made at previous oppositions. In consequence I believe it will be possible in future to foretell, with something approaching the certainty of our esteemed weather bureau's prognostications, not indeed what the weather will be on Mars, for it seems doubtful if Mars has much of what

we call weather to prognosticate, but the aspect of any part of the planet at any given time.

The changes in appearance presented by the planet here to be described refer primarily not to the melting of the polar snows, except as such melting forms the necessary preliminary to what follows, but to the subsequent changes in look of the surface itself. To their exposition, however, the polar phenomena become inseperable adjuncts since they are inevitable ancillaries to the result.

With the familiar melting of the polar snow-cap, therefore, this account properly begins, since with it begihs the yearly round of the planet's life. With the melting of our own Arctic or Antarctic cap might, similarly, be said to begin the Earth's annual activity. But there appears to be one important difference here at the very outset between the two planets. In the case of the Earth the relation of the melting of its polar snows to the awakening of surface activity is chiefly one of *post hoc* simply; in the case of Mars it seems to be one of *propter hoc* as well. For unlike the Earth which has water to spare, Mars is apparently in straits for the article and has to draw on its polar resorvoir for its annual supply. To the melting of its polar cap and to the transference of the water thus annually set free to go its rounds seems to depend all the phenomena upon the surface of the planet.

The observations upon which this deduction is based extend over a period of more than five months; from the last day of May of this year to the seventh of November. They cover the regions from the south pole to about latitude thirty north. That analogous changes to those recorded, differing, however, in certain marked particulars, occur six Martian months later in he planet's northern hemisphere, I hold to be probable. For though it is likely that the general system is one for the whole planet, it is also likely that the distribution of the planet's surface details alters the action to some extent.

To an appreciation of the meaning of the changes it is to be borne in mind throughout that the vernal equinox of Mars' southern hemisphere occurred on April 7th, 1894; the summer solstice of the same hemisphere on Aug. 31st; and that its autumnal equinox will take place on Feb. 7, 1895.

On the 31st day of last May, therefore, it was toward the end of April on Mars. The south polar cap was then very large, upwards of 45 degrees across, and already in active process of melting. The tilt of the planet's axis toward the Earth enabled it to be well seen, and disclosed the fact that it was bordered

persistently by a dark band, broader in some places than in others, but keeping pace with the snow's retreat. The average breadth of the dark band was, in June, 220 miles. It was the darkest marking on the disk and was blue.

As the season advanced and the snow cap diminished its dark girdle diminished in breadth, with fluctuations dependent doubtless on the draining capacity of the ground. In August it showed as a slender dark thread.

That it was water is practically beyond a doubt. That it was of the color of water; that it so faithfully followed the melting of the snow; and that it subsequently vanished are three independent facts mutually confirmatory to this conclusion.

That it was the darkest blue marking on the disk implies that it was the deepest body of water on the planet. That it subsequently entirely drained off implies that its depth could not have been very great. Both facts together make a first presumption in favor of its being not only the chief body of water on the planet but the only one of any size.

This polar sea plays *deus ex machina* to all that follows.

So soon as the melting of the snow was well under way, long straits of deeper tint than their surroundings made their appearance in the midst of the dark areas. I did not see them come, but as I have since seen them go, it is evident that they must have come. They were already there on the last day of May. The most conspicuous of them lay between Noachis and Hellas in the Mare Australe and thence through the Mare Erythæum to the Hour-glass Sea (Syrtis Major). The next most conspicuous one came down between Hellas and Ansonia. Although these straits were very distinguishably darker than the rest of the seas through which they ran, the seas themselves where then at their darkest. The fact that these straits ran through the seas suffices to raise a second doubt whether the seas be seas. The subsequent behavior of the so-called seas renders their aquatic character still more doubtful.

The appearance of things at this initial stage of the Martian Nile-like inundation is shown in Fig. 1. That the seas were then at their darkest is probably due both to the fact that some water had already found its way down from the pole and also to the fact that moisture had been deposited there on the water's journey up and had quickened the vegetation of those relatively amphibious lands. The date which this drawing represents was June 1st, that is, about the Martian first of May.

For some time the dark areas continued largely unchanged in

appearance; during, that is, the earlier and most extensive part of the melting of the snow-cap. After this their history became one long chronicle of drying up. Their lighter parts grew lighter and their darker ones less dark. For even to start with they were composed of every grade of tint. Indeed one of the most significant features about them was that at this epoch it was impossible to fix any definite boundaries to the south temperate chain of islands. The light areas and the dark ones merged indistinguishably into each other. Viewed from the standpoint of maps of Mars, the landmarks of this whole region lay obliterated by a deluge; not directly but indirectly. Probably the region was in various stages of vegetal fertility in consequence of a comparatively small body of water then inundating it. The color of the dark areas was then and is now, to my eye, a bluish-green; quite unmistakably so. This tint gradually faded out to give place to orange-yellow.

The first marked sign of change was the reappearance of Hesperia. This took place in July. In August, when I saw it, its presence was marked. As yet nothing could be seen of Atlantis. It was not till the end of October, on the 30th, that I caught sight of it. About the same time the straits between the islands Zanthus, Scamander, Ascanias and Simois came out saliently dark, a darkness due to contrast.

Meanwhile the history of Hesperia continued to be instructive. From having been invisible in June and conspicuous in August, it returned in October to a mid-position between the two. Figs. 3, 4 and 5 show it in its three metamorphoses. Vacillating as these fluctuations may seem at first sight they will all be found to be due to one progressive change in the same direction, a change that showed itself first in Hesperia itself and then in the regions round about it. From June to August Hesperia changed from a previous blue-green, indistinguishable from its surroundings, to yellow, the parts adjacent remaining much as before. In consequence the peninsula stood out in marked contrast to the still deep blue-green regions by its side. Later the surroundings themselves faded and their change had the effect of once more partially obliterating Hesperia.

While Hesperia was thus causing itself to be noticed, all the rest of the south temperate zone, as we may call it for identification's sake, was unobtrusively pursuing the same course. Whereas in June all that part of the disk comprising the two Thyle, Argyre II and like latitudes was chiefly blue-green, by October it had become chiefly yellow. The separate identity of these is-

lands became then for the first time apparent. Still further south what had been first snow and then water turned to yellow land. This metamorphosis went on till on Oct. 13th the remains of the snow-cap entirely, or practically entirely, disappeared; the first complete disappearance of it on record. After this event the whole south polar region was one yellow stretch.

Toward the end of October a strange and, for observational purposes, distressing phenomenon took place. What remained of the more southern dark regions proceeded unexpectedly to fade in tint throughout. This was first noticeable in the Cimmerium Sea; then in the Sea of the Sirens and in November in the Mare Erythraeum about the Lake of the Sun. This fading steadily progressed until it got so far that in poor seeing the markings were almost imperceptible and the planet presented a nearly uniform yellow disk.

Now this fading out of the dark areas is a highly significant fact, with a direct bearing upon their constitution. For it is not simply that portions of the planet's surface have changed tint but that taking the disk in its entirety, the amount of the blue-green upon it has diminished and that of the orange-yellow proportionately increased. Mars appears more Martian than he did in June. Now if the blue-green areas represent water, where has this water gone? Nowhere on the visible disk. That is certain. For in that case the amount of the dark areas should not be perceptibly lessened; which it is. Nor can it all very well have gone to that part of the planet that is hidden from view. For Schiaparelli's observations in 1882 go to show that the northern snow-cap forms late; one month *after* the vernal equinox of the northern hemisphere on that year. Since therefore the water fails to prove an alibi, presumption is instantly raised in favor of the alternate hypothesis, that the blue-green areas represent vegetation, fertilized by a comparatively small amount of water whose direct presence or absence is not very perceptible to us, but whose indirect effects are. For vegetation might change from green to yellow without requiring any corresponding inverse change elsewhere.

Now though the passage of the water may not be traced by its amount; there is a further change which has lately appeared on the disk which hints at what has become of it. The canals have darkened. What is more their darkening has pursued a perfectly definite course, proceeding steadily from south to north.

The following observations of mine show first: that the canals are not equally visible at all times; and secondly: that their invisibility is a matter of the Martian seasons.

In June the canals were very faint markings indeed. The least faint were those in the Solis Lacus region. As the planet approached us they all became naturally easier to make out but until October no change apparently occurred in any of them except those in the region about the Lake of the Sun. These by September were already dark. In October they began to show symptoms of growing lighter again. At the next presentation in November they showed further signs of change though not differing as yet very unmistakably in tint. Meanwhile when the Sinus Titanum region came round in November I, found that its canals had begun likewise to darken. Figs. 6 and 7 show the change that had taken place. The canals were not only darker relatively to the Mare Cimmerium and the Mare Sirenum than they had been, but actually darker themselves. In the next few nights I found the more northern canals about Ceraunius had followed suit. They had darkened relatively to the southern ones about the Lake of the Sun.

Now on looking at a map of Mars, it will be seen that the Solis Lacus region is that part of the continental areas which lies nearest the south pole. Similarly that the region about Sinus Titanum is the next farthest south. The matter of latitude therefore affects the point.

The same progressive change in the visibility of the canals is shown in Figs. 1, 2 and 3. By October 30th the canals to the northwest of Hesperia had become more pronounced.

The canals and so-called lakes share therefore in the annual metamorphosis, with a season change dependent in a general way upon their latitudes. A wave of deepening tint passes successively through the blue-green regions from south to north, timed to the seasonal wave that travels from pole to pole. From being pale in winter, their color comes with the spring, deepens through the summer and dies out again in the autumn. In any given locality the change comes early or late in proportion as the place lies, other things equal, distant from the pole.

That this change of tint is due indirectly to water and directly to the vegetation that water induces seems probable. For just as there is great difficulty in disposing of the water on the first supposition so the second would lead us to expect just the phenomena observed. We may therefore conclude that the seas of Mars are probably midway in evolution between the seas of Earth and the seas of the Moon. No longer bodies of water they have not yet become barren ocean beds but are in that half way stage of the process when their low level helps them catch

PLATE XLII.

SOUTH.

Fig. 1.—Syrtis Major
At June Presentation.
Long. 294°
Lat. centre of Disk—24°.
(Marth.)

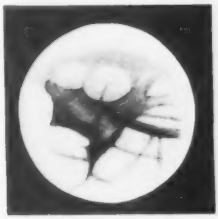


Fig. 2.—Syrtis Major
At October Presentation.
Long. 310°
Lat. centre of Disk—30°
(Marth.)

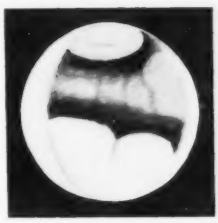


Fig. 3.—Hesperia
At June Presentation.
Long. 240°
Lat. centre of Disk—24°
(Marth.)

Fig. 4.—Hesperia
At August Presentation.
Long. 237°
Lat. centre of Disk—17°
(Marth.)

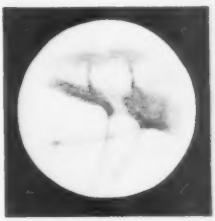


Fig. 5.—Hesperia
At October Presentation.
Long. 237°
Lat. centre of Disk—21°
(Marth.)

NORTH.

Fig. 6.—Sinus Titanum
At June Presentation.
Long. 146°
Lat. centre of Disk—240°
(Marth.)

Fig. 7.—Sinus Titanum
At November Presentation.
Long. 161°
Lat. centre of Disk—22°
(Marth)

XUM

what water still voyages upon the planet's surface though they have long since parted with their own.

As for the lakes and canals I defer what I have to say about them to a later paper. For the purposes of this one it is enough that they prove to be, like the seas, functions of the seasons.

Throughout all these interesting changes that follow the seasons across the face of Mars there is but one feature approaching permanence: the great continental areas. Except for a possible variation in brightness here and there this great area has remained unchanged. Like the reddish desert regions of our Earth its color and immutability point to like character for cause. It does not change because it is already past such possibility. It is one vast desert waste.

LOWELL OBSERVATORY,
Nov. 11, 1894.

THE FORM OF THE DISC OF THE III SATELLITE AND PHENOMENA OF THE OCCULTATION OF A SATELLITE OF JUPITER.

E. E. BARNARD.

In ASTRONOMY AND ASTRO-PHYSICS for 1894, November, page 728, Professor William H. Pickering predicts the probable elongation of the disc of the 3rd satellite of Jupiter.

On that date (Nov. 5) I examined the satellite closely with all powers up to 1000 on the 36-inch with good seeing. From 14^h 0^m to 15^h 10^m standard Pacific time frequent examinations of the satellite showed it to be round, with the eyes held in different position angles.

The usual markings were seen on it, but no distortion of the disc was apparent.

Professor W. H. Pickering has also called attention to the appearance of a twilight or glow of light at the limb of Jupiter just preceding the first appearance of a satellite, when coming out from occultation, which would prove a dense atmosphere to Jupiter, extending above the visible surface. When the satellite has been cut by the limb of Jupiter he has also observed a distortion of the small disc as if seen through a refracting medium.

I had never witnessed these phenomena, and on two occasions lately (when the opportunity offered) have watched specially and carefully for them with the 36-inch. Both these observations were of satellite I at emergence from occultation and the seeing in each case was all but perfect.

EMERGENCE OF I FROM OCCULTATION.

1894, Oct. 8, $14^h\ 37^m\ 31^s$ first glimpse of I.
1894, Oct. 8, $14^h\ 40^m\ 08^s$ just free from Jupiter.

The limb of Jupiter was sharp and clear. Watched carefully for any appearance of "down" but no trace of it. The satellite was first seen as the tiniest white speck and gradually grew to rotundity at the last contact. There was no distortion of the disc of I. There was no transparency of the limb of Jupiter. The satellite was sharply and clearly cut, the limb of the planet being strongly and sharply contrasted against the face of I. The reappearance was at a point on the limb where the north reddish belt would be.

EMERGENCE OF I FROM OCCULTATION, STANDARD PACIFIC TIME.

1894 Oct. 15, $16^h\ 29^m\ 48^s$ one-half out.
$16^h\ 31^m\ 38^s$ last contact.

Watched carefully in this case also for any appearance of "down," for any distortion of the satellite and for any transparency of the limb of Jupiter. None of these phenomena was present, the seeing was fine aud the limb of Jupiter clear and sharp on the face of the satellite, which was first caught as the tiniest speck of light—the time of the first glimpse was not recorded as I wished to devote my whole attention to the progress of the reappearance.

These observations show that on these two occasions, at least, there was no perceptible illumination, a Jovian atmosphere preceding the rising of the satellite. There was no distortion of the disc of the satellite at any time during the reappearance. The limb of Jupiter was perfectly and absolutely opaque,—as it has always been at every observation that I have made of the occultation of a satellite with instruments varying all the way from 5 inches to 36 inches.

On this latter subject, *i. e.*, the transparency of the limb of Jupiter—I have had something to say in ASTRONOMY AND ASTRO-PHYSICS for April, 1894, page 272, and June, 1894, page 438.

I would simply quote here from the first of these papers and when I quote it I unhesitatingly endorse and emphasize the statements.

"These observations have been made with care, with the most powerful telescope that to-day can be applied to such observations, and the limb of Jupiter has appeared perfectly opaque—as at all previous observations with smaller telescopes.

XUM

"I think it is high time that astronomers reject the idea that the satellites of Jupiter can be seen through his limb at occultation. When the seeing is bad there is a spurious limb to Jupiter that well might give the appearance of transparency at the occultation of a satellite. But under first class conditions the limb of Jupiter is perfectly opaque.

"It is quibbling and begging the question altogether to say that the phenomenon of transparency may be a rare one and so have escaped my observation."

There are too many things of this kind (transparency of the limb of Jupiter) that have gained currency in astronomical literature. It is the duty of every conscientious observer to see that they are weeded out, and astronomy will be all the better and purer for the purging.

LICK OBSERVATORY, Nov. 9, 1894.

THE DISTRIBUTION OF HEAT ON THE SUN.*

W. H. S. MONCK.

That the present temperature of the Sun is partly at least due to shrinkage and the development of heat in the process must, I think, be admitted, but it seems to me that it leads to some consequences not generally recognized which I propose to indicate briefly.

Starting from a position of equilibrium, *i. e.*, which would continue without alteration if we could prevent heat from entering or leaving the Sun, any further shrinking can only be due to cooling, or rather, loss of heat. The Sun probably reached this position of equilibrium ages ago. The assumption that it is losing more heat than it receives from without seems to be very generally made, and is so far correct, that it certainly parts with more heat than it is known to receive from without. The shrinkage thus caused is, of course, in reality a single steady process, but for convenience we may suppose it to occur in three stages: 1. A contraction or falling in of the solar matter towards the centre of gravity due to cooling or loss of heat. 2. Heat developed by this contraction or falling in. 3. Expansion caused by the heat thus developed. This expansion can never, I apprehend, be equal to the original contraction and the effect of (2) is therefore

* Communicated by the author.

merely to render the contraction slower than it would be if no heat were developed by the contraction.

So far as heat received from without is concerned, the temperature of the Sun cannot be much affected thereby. No star is likely to have remained near enough to the Sun for a sufficient time to render the part of the Sun on which its light fell sensibly hotter than the part on which it did not fall, nor does there appear to be any arrangement of stars in the aggregate that would render one portion of the Sun hotter than another. As to the heat derived from meteors falling into the Sun we can only speculate, but I doubt if it would produce any sensible difference in the temperature of different parts of the solar surface.

But the Sun is a rotating body, and the centrifugal force of rotation is different at different parts of its surface. It lessens the force of gravity everywhere but more so at the solar equator than in the neighborhood of the solar poles. Now the heat developed by contraction depends on the force of gravity at the place where the contraction takes place. Shrinkage developes less heat at the solar equator than near the solar poles, and a state of things must arise which completely inverts what we find on the Earth. *The Sun is hotter at the poles than at the equator.*

There are two ways in which this superior heat might be ascertained. One is by direct measurement. Test the heat, light or chemical action of a part of the Sun near the equator and another part near the pole, both being at equal distances from the solar limb. But the detection of no measureable difference would not decide the question. The photosphere is probably to be assimilated not to the solid body of the Earth but to our terrestrial clouds. The effect of the greater heat at the poles may not be to make these clouds hotter but to make them float at greater elevations in the solar atmosphere. This, if it occurred, could be detected in another way. The Sun would not exhibit that amount of flattening at the poles which we might expect from the velocity of its rotation. No flattening has been hitherto observed. But the centrifugal force at the Sun's equator is very small compared with gravity. It is only by its continuous action for perhaps millions of years that a considerable difference of temperature between the poles and the equator could be established.

A difference in temperature between the poles and the equator would necessarily set up air-currents in a body possessing an atmosphere as the Sun does. But in these currents our trade-winds and anti-trades would of course be reversed. The cooler air (I

use this term *air* for the gases which form the solar atmosphere) would flow in below from the equator towards the poles, and the hotter air from the poles to the equator would flow over in upper currents. If the sunspots or any other visible peculiarities were connected with these currents, they would appear to be moving from the pole to the equator if they belonged to the upper-current, and from the equator to the pole if they belonged to the under-current. Those in the upper-current would take longer to affect a revolution than the Sun's true period of rotation, while those in the under-current would effect a revolution in less time. From this point of view sunspots present some indications of being phenomena of the upper-currents. No such spots are found in the vicinity of the poles. This would be a necessary consequence of the current-theory. No system of trades and anti-trades could extend to the vicinity of the poles. But I can offer no suggestion with regard to the periodicity of the sunspot periods.

The principles here laid down would apply to the cooling of any rotating body; but the great supply of heat in the planets is derived by radiation from the Sun while shrinkage has but a slight effect on the phenomena. In the case of the Earth it probably somewhat lessens the difference in temperature between the equator and the poles which is caused by the Sun's radiation. With Jupiter perhaps the effect may be different. The planet is more distant from the Sun, composed of lighter materials, and rotates more rapidly on its axis. Possibly, too, the condition of equilibrium with which I started has not yet been attained in the case of Jupiter. The planet undoubtedly sometimes presents phenomena analogous to the sunspots, and the rotation-period of the planet derived from one of these spots differs from that derived from another. But neither these Jovian spots nor the sunspots exhibit the unmistakable changes of latitude which might be expected if they were connected with air-currents. Perhaps they are only formed near the limits of a current or the points where conflicting currents meet.

Comparing the Sun with fixed stars, more rapid rotation would exaggerate the difference between the polar and equatorial temperatures and the force of the two systems of currents; and of course if the phenomena of sunspots are connected with these currents, it would exaggerate them also. A spectrum resembling that of a sunspot might, therefore, be expected in the case of stars which rotate with great velocity: and if there is also a periodicity in the appearance of the spots, the star would probably be periodically variable in its light. Variation might thus arise

not from any peculiarity either in the chemical composition or in the temperature of the star, but from the rapidity of its rotation and consequent difference of temperature between its poles and its equator. Some of our terrestrial geysers afford examples of periodical eruptions arising from continuous causes. They are not indeed closely analogous to the phenomena which I have been considering, but may nevertheless suggest that periodicity in the effect does not necessarily suppose periodicity in the cause; and moreover the sunspot maxima do not appear to be strictly periodic.

THE TWENTY-INCH EQUATORIAL OF THE CHAMBERLIN OBSERVATORY.

H. A. HOWE.

Having been requested by the editor of *Astronomy and Astro-Physics* to give further details about the Chamberlin telescope, the writer begs to call attention to the following:

The Tripod-base. In the article of last month mention was made of the tripod on which the instrument stands. The word tripod conveys the idea of instability, when used in connection with so large a mounting. Though Mr. Saegmuller has used the same form of support for the 12-inch telescopes at Providence and Georgetown, where it has given entire satisfaction, no description of it has yet appeared. Around the periphery of a hollow cylinder, which is 5 ft. in diameter and 2ft. high, are set at equidistant intervals 3 pairs of isosceles right triangles. The plane of each triangle is vertical, and one of its perpendicular sides coincides with an element of the cylinder. The triangles of each pair are 6 inches apart. Between the outermost vertices of each pair of triangles runs one of the large vertical supporting bolts which were described last month. These stout triangles may be considered as the legs of the tripod. When the weight of the instrument is on the tripod there is a tendency to tear the cylinder asunder at its lower edge. This is resisted by a horizontal flange about 9 inches wide, running entirely around the base of the cylinder and underneath the triangles. The entire tripod, begin a single heavy casting weighing 3 tons, is extremely rigid.

The Pillar. The form of the pillar deserves commendation. Its circular horizontal cross-section is a pledge of rigidity in azimuth. Its sudden flare at the base, where the iron is over 6 inches thick,

XUM

allows its upper portion to be small, so that observations can be made in or near the zenith, without having the eye-end strike it. For observations near the pole it would be difficult to get the observing chair far enough north, in case the pillar were long north and south, as are most of the large pillars in this country.

The Clamps and Slow Motions. The declination clamp and slow motion is of the customary toothed sector form. The same principle is applied to the construction of the right ascension clamp and slow motion. The large worm wheel at the upper end of the polar axis engages, as usual, with a worm driven by the clock, and cannot be clamped directly to the polar axis; it always rides loosely upon that axis. Above the wormwheel, that is, between it and the declination sleeve lies a toothed sector, similar to the one for declination. The toothed end of the sector engages with a worm mounted on the declination sleeve, close by the small end of the declination axis. The other end of the sector embraces a hub on the upper side of the big wormwheel, and encircles the polar axis, though it does not touch it. When the sector is clamped to the hub of the wormwheel the polar axis cannot revolve, unless the clock drives it, or the slow motion worm which engages with the sector is turned. To render it possible to clamp the telescope and give it a slow motion, in right ascension, when the observer is at the eye-end, the declination axis is made hollow. A stout steel tube, inside of which lies a cylindrical rod, fills this hollow. The rod has a small bevel gear at each extremity. The tube carries a bevel gear at the end inside of the telescope tube, and a sprocket wheel at the other end. The sprocket is encircled by a small chain by means of which the right ascension clamp is actuated. The clamp and slow motion rods start at the eye-end, enter the telescope and engage with the small bevel gears just mentioned. The motions are then carried through the declination axis by the internal tube and rod, and thus communicated to the sector-worm and clamp.

The advantage of this mechanism is that the instrument is held strongly, and that the slow motion is smooth, delicate, and almost free from back-lash. The disadvantage is that there is considerable friction when the instrument is moved by hand in right ascension. For one has then to overcome not only the friction of the wormwheel rubbing on the polar axis, but the friction of the sector on the hub of the wormwheel. If a copious supply of oil be used to overcome this sector-friction, the clamp will not grip well. For small equatorials no appreciable disadvantage arises from this source, but in a large one every extra drain upon the

observer's strength is to be avoided. So admirable are the anti-friction wheels and balls with which Mr. Saegmuller has equipped the polar axis, that most of the friction encountered in giving the instrument rapid motion in hour-angle is due to the rubbing of the worm-wheel and of the sector. It is evident that this friction does not come into play when the clock drives the instrument.

It would not be difficult to mount the wormwheel on ball-bearings, but if the sector were mounted in like manner, the efficiency of the clamp would be diminished, though by no means destroyed. However, it would not be difficult to devise a powerful and simple clamp, even if the sector were equipped with ball-bearings.

Finding Circles. The mechanism of the finding circles near the handwheels on the south side of the pillar is unique and ingenious. It is driven by the two vertical rods at the lower ends of which are the handwheels for quick motion in right ascension and declination. The large cylindrical box containing the mechanism hangs between these rods, and is supported by them on ball-bearing collars. The rods themselves are hung from the top by means of ball-bearing collars, and are held truly vertical by grinding collars just above the handwheels. The eastern rod engages, by the help of subsidiary gearing, with a large bevel gear on the polar axis, just below the hour circle. The western rod similarly turns a stout tube of Mannesman steel which runs up through the polar axis, and carries at its upper end a bevel gear which meshes with another bevel gear encircling the declination axis. A little consideration will show that if the instrument be revolved on the polar axis both rods must turn, while a rotation on the declination axis causes the western rod only to turn.

The conditions of the mechanical problem so beautifully solved by Mr. Saegmuller, in the construction of this system of finding circles, may be stated as follows:

(*a*) When the instrument rotates on the declination axis, and the western rod alone is turning, the declination pointer must move along its dial, and the right ascension pointer must be stationary.

(*b*) When the instrument is rotating on the polar axis and both rods are turning, the declination pointer must be at rest, and the right ascension pointer must move.

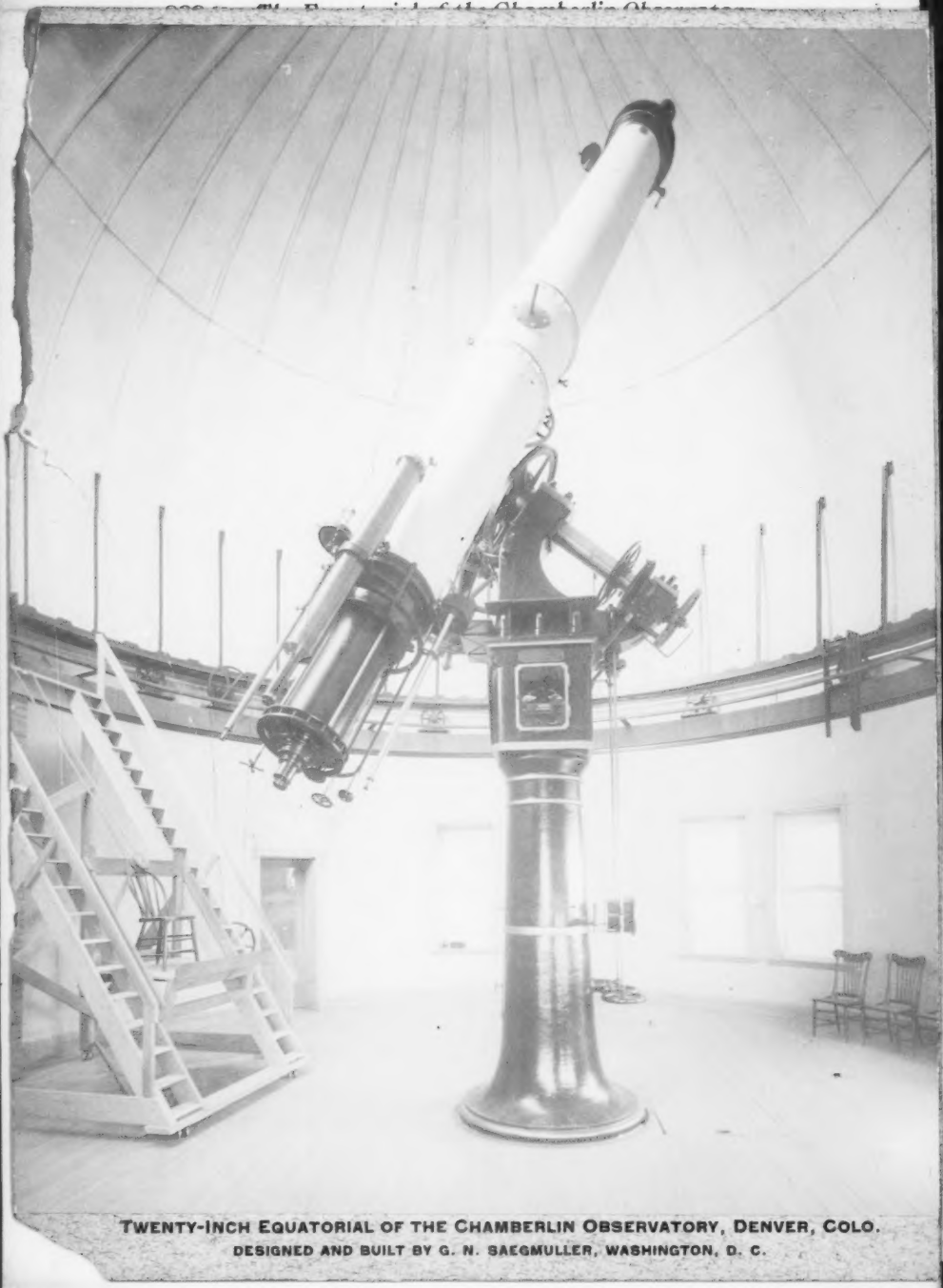
(*c*) When the driving clock is moving the instrument, and both rods are turning, the reading of neither dial must change.

(*d*) When the instrument is at rest the reading of the right ascension dial must change continually.

XUM

KUM

XUM



TWENTY-INCH EQUATORIAL OF THE CHAMBERLIN OBSERVATORY, DENVER, COLO.
DESIGNED AND BUILT BY G. N. SAEGMULLER, WASHINGTON, D. C.

XUM

KUM

XUM

(*e*) When the instrument is moving on both axes, each pointer must move with double the angular velocity of the corresponding axis, and in all possible positions of the telescope the dials must give the right ascension and declination of the object toward which the telescope is directed. The diagram shows the details of the mechanism, with the exception of the clock which drives the right ascension dial.

The Micrometer. In the former article there was one criticism of this attachment, on the ground that the position circle was hard to read, when the box was directly over the verniers.

Having now used the micrometer a little, the writer finds that this difficulty is hardly worth mentioning, in case only one vernier is to be read, which is generally sufficient. For that end of the box on which the illuminating lamp is fastened is so high up that one can look under it and read the circle easily. The writer has seen no other micrometer as fine as this one, except the one built by the same maker for the Lick telescope.

Electric Illumination. Since the previous description of this was written, a number of experiments have been made, the results of which may be of interest. In illuminating the verniers of the main circles, which are read, from quite a distance, by telescopes, small electric lamps having clear bulbs are not satisfactory, because they illuminate strongly only a small portion of the vernier. After experimenting vainly for some hours with 2 c. p. lamps assisted by reflectors and lenses, 6 c. p. lamps with frosted bulbs were fixed upon for the declination verniers, and ordinary 16 c. p. house lamps, set with the long portion of the filament parallel to the edge of the vernier, were used for the hour circle. The 6 c. p. lamps were set close to the verniers, and the 16 c. p. about a foot away. The axis of symmetry of each 6 c. p. lamp bulb is parallel to the edge of the vernier, and the lamp is backed by a semi-cylindrical reflector of bright tin. The large rough setting circles on the declination axis and on the north face of the clock-box are illuminated by 2 c. p. lamps with clear bulbs.

The general principle is that a bright reflecting surface, like a silver circle, is to be lit up by a frosted lamp, while a dull surface fares better if the lamp-bulb be clear.

For the micrometer wires a 2 c. p. clear bulb lamp is used, and its intensity is diminished by a small coil of german silver wire, giving a resistance variable at will. This is preferable to using a 1 c. p. lamp, which gets very hot. Instead of employing a red shade-glass, one may purchase of the Edison Miniature and Decorative Lamp Co. (Harrison, N. J.) lamps with ruby bulbs.

But each costs twenty cents more than one with a clear bulb. In ordering small lamps of this company one must state that *battery* lamps are desired, if one of Mr. Richardson's converters furnishes the current. It is convenient to have all lamps of nearly the same voltage. Otherwise it may be necessary to calibrate the system by introducing small pieces of resistance wire into the circuits of lamps having low voltage.

Details of Vertical Friction Rollers.—These rollers were mentioned in last month's article; they work so satisfactorily, and are withal so simple that further details concerning them may not be amiss. Directly below the main wormwheel on the polar axis is a collar of steel, the outer surface of which is conical, like the wheel A in Fig. 4 of Mr. Wadsworth's article in the last preceding number of this magazine. Mr. Saegmuller's conical collar is only a little larger than the polar axis, and is supported by 6 hardened steel rollers (whose flat sides lie in the plane of the prime vertical), resting side by side on a horizontal axis, and loose upon that axis. The axis rests upon a bearing composed of small hardened steel cylinders. To avoid sliding friction, where the rollers press against the collar, it would theoretically be necessary that the edge of each roller should be conical in form, like roller B in Mr. Wadsworth's Fig. 4. The apex of this conical surface should coincide with the apex of the conical surface of the collar. But this would necessitate having the axis of B inclined to the horizon, in case the lowest element of the conical surface of A were horizontal, as it should be: this would be objectionable if a large weight were to be supported.

Mr. Saegmuller makes the edge of each friction roller slightly rounded, so that contact with the collar takes place theoretically along a line only. The yielding of the hard steel surfaces causes this line in practice to broaden into a narrow belt, but the sliding friction thus caused is not practically significant. There is also axle friction, because the northernmost roller turns a little faster than the southernmost. But the bearing-surfaces are so hard, and the amount of sliding so small, that no injurious wear is anticipated.

XUM

Astro-Physics.

THE ASTROPHYSICAL JOURNAL.

GEORGE E. HALE.

In a paper bearing the above title, published in the first number of ASTRONOMY AND ASTRO-PHYSICS (January, 1892), the reasons which had prompted the publication of a journal of astronomical physics were enumerated, and evidence was adduced to show that considerable support might be expected for such a venture. It had been my intention to establish a separate astrophysical journal, but the uncertainty of such an undertaking led to an acceptance of Professor Payne's proposal of a union with the *Sidereal Messenger*, and ASTRONOMY AND ASTRO-PHYSICS was the result. The contents of the thirty numbers published during the three years which have elapsed since that time offer sufficient testimony to the usefulness of the composite journal. From the outset the editorial supervision of the departments of *General Astronomy* and *Astro-Physics* has been kept entirely distinct. The policy of the latter department has been determined by myself and my associates, Professors Keeler, Crew and Ames, while the selection of all other matter published in the journal has been made by Professor Payne and those who were associated with him. No attempt has been made to draw a hard and fast line between the two departments. Had this been done, and a strict definition of "astrophysics" adhered to, a large part of the matter published under *General Astronomy* would have appeared in the other department of the journal. It was thought best, however, to confine the scope of *Astro-Physics* to the more technical subjects connected for the most part with spectroscopic work.

In returning to the original idea of a purely astrophysical journal we are simply following out a long-cherished plan. Few who appreciate the true scope of astrophysics, and have its best interests at heart, will deny the advisability of devoting an entire journal to this, the most fascinating and at the same time the most rapidly advancing department of astronomical research. In spite of the existence of physical and astronomical journals of the highest class, the astrophysicist or spectroscopist is at a loss to know where to publish in order to reach the audience he desires. Should he choose an astronomical journal, he will find that his paper will remain unread and unknown by a very large majority of physicists—the very men who are perhaps best com-

petent to appreciate its true value. A purely physical journal is not less evidently an unsuitable place for papers treating of solar or stellar investigations, even though these investigations be prosecuted by the methods of the physical laboratory. Recent papers on the radiation of gases and the validity of Kirchhoff's law have all appeared in physical journals, but the subject is one not less interesting to the astronomer than to the physicist. The same might be said of scores of other papers dealing with spectroscopic, bolometric, photographic and photometric researches conducted in the laboratory, but finding their most important applications in the elucidation of astronomical phenomena. The astronomer and physicist should be able to meet on common ground, and this only an astrophysical journal can supply.

During a recent visit to many of the observatories and spectroscopic laboratories of Europe, the writer enjoyed an excellent opportunity to discuss with both astronomers and physicists the plan of founding such a journal. At Potsdam Professor H. C. Vogel, Director of the Astrophysical Observatory, and Professors Scheiner, Müller and Kempf were found to be heartily in favor of the proposed journal, and ready to promise their support and coöperation. In a plan of publication formulated at Berlin it was decided that five Associate Editors be chosen to represent Germany, Great Britain, France, Italy and Sweden on the editorial staff, for it was felt from the first that unless the journal were made truly international in character it could not be a success. Professor Vogel readily consented to be the Associate Editor for Germany. In subsequent visits to Rome, Paris and London the plans of the journal were discussed at length with Professor P. Tacchini, Professor M. A. Cornu and Dr. William Huggins. Everywhere the most cordial assurances of support and coöperation were received, and before my return to America the general plan of the journal had been decided upon, and the European members of the Board of Associate Editors chosen as follows: Professor M. A. Cornu, Ecôle Polytechnique, Paris; Professor N. C. Dunèr, Astronomiska Observatorium, Upsala; Dr. William Huggins, Tulse Hill Observatory, London; Professor P. Tacchini, R. Osservatorio del Collegio Romano, Rome; Professor H. C. Vogel, Astrophysikalisches Observatorium, Potsdam. Subsequently five Associate Editors were secured in the United States: Professor C. S. Hastings, Yale University; Professor A. A. Michelson, University of Chicago; Professor E. C. Pickering, Harvard College Observatory; Professor H. A. Rowland, Johns Hopkins University; Professor C. A. Young, Princeton University.

XUM

Professor James E. Keeler of Allegheny Observatory, whose association in the editorial management of ASTRONOMY AND ASTRO-PHYSICS has done so much for this journal, has agreed to join the writer in editing THE ASTROPHYSICAL JOURNAL. Professor Henry Crew of Northwestern University and Professor Joseph S. Ames of Johns Hopkins University will continue the valuable work they have hitherto carried on in connection with ASTRONOMY AND ASTRO-PHYSICS as Assistant Editors of the new journal, and Professor F. L. O. Wadsworth of the University of Chicago, Professor Edwin B. Frost of Dartmouth College, and Professor W. W. Campbell of the Lick Observatory have promised to assist in the same capacity. In addition to this exceptional editorial coöperation—in itself quite sufficient to make THE ASTROPHYSICAL JOURNAL truly international in character—we are fortunate in having promises of assistance from many astronomers and physicists in Europe and America.

It must not be supposed that THE ASTROPHYSICAL JOURNAL will deal only with the astronomical applications of the spectroscope. On the contrary, the scope of the JOURNAL will be quite as broad as that of ASTRONOMY AND ASTRO-PHYSICS has been, for while papers dealing only with questions of celestial mechanics and measures of the positions of the heavenly bodies will not fall within it, they will be replaced by articles treating of laboratory researches closely allied to the investigations of astronomical physics. Drawings, photographs, descriptions and theories of the Sun, Moon, planets, satellites, comets, shooting stars, star clusters, nebulæ and the Milky Way will all be considered as coming within the scope of the new journal. So too will observations of variable stars, photometric determinations of stellar magnitudes and planetary albedo, measurements of solar radiation and atmospheric absorption, observations of the phenomena of lunar and solar eclipses, and the numerous applications of the spectroscope in astronomy. The importance of supplying a common place of publication for papers on both the observatory and laboratory applications of physical methods of research has already been pointed out. For this purpose much space will be devoted to articles on wave-length determinations of the lines in solar, metallic and gaseous spectra, bolometric and bolographic work, spectral photometry, experiments on radiation and absorption, photographic researches in the ultra-red and ultra-violet, studies of the relations of the lines in different spectra, interference and diffraction phenomena, and theoretical work in certain branches of optics, heat, electricity and other departments

of physics. In pursuance of the plan which seems to have met with favor in ASTRONOMY AND ASTRO-PHYSICS, the series of papers on the modern spectroscope will be continued, and accompanied by articles on telescopes, heliostats, bolometers, photometers and other instruments and apparatus used in such investigations as those mentioned above. Astrophysical and spectroscopic observatories and laboratories will also be fully illustrated and described.

Special attention will be given to the reproduction of the latest photographs of astronomical and physical phenomena. By reason of their relations with the observatories and laboratories of Europe and America, the editors will always have the best photographs at their disposal.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English.

In the department of *Minor Contributions and Notes*, subjects other than those named in the above list of topics, but belonging to closely related fields of investigation, may find a place.

It is intended to publish in each number a *Bibliography of Astrophysics*, in which will be found the titles of all recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to Professors Hale and Keeler.

These and other details of the plan of publication of THE ASTROPHYSICAL JOURNAL were decided upon at a meeting of the American members of the Board of Editors held in New York on November 2, 1894. Professors Young, Pickering, Rowland, Michelson, Hastings, Keeler and Hale were present. It was voted that a meeting of the Board of Editors be held annually, for the discussion of matters relating to the JOURNAL.

ASTRONOMY AND ASTRO PHYSICS has been purchased from Professor Payne by the University of Chicago, and THE ASTROPHYSICAL JOURNAL will be a continuation of it in a slightly different form, beginning with the January number. It is hoped that those whose subscription to ASTRONOMY AND ASTRO-PHYSICS expires with the present number will subscribe at once for THE ASTROPHYSICAL JOURNAL. If the subscription extends into 1895 the JOURNAL will be sent until the time expires. The annual subscription price (for ten numbers) will remain $4.00 for the United

States, Canada and Mexico. In other countries of the Postal Union the price is 18 shillings. Subscriptions should be sent to *The University of Chicago, University Press Division, Chicago, Illinois.* All Eutopean subscriptions should be sent to the sole foreign agents, Messrs. Wm. Wesley & Son, 28 Essex St. Strand, London.

All papers for publication and correspondence relating to contributions should be addressed to *George E. Hale, Kenwood Observatory, Chicago, Illinois.*

THE MODERN SPECTROSCOPE.

IX.

FIXED-ARM SPECTROSCOPES.

FRANK L. O. WADSWORTH.

In prismatic spectroscopes and spectrometers of the usual construction it is necessary, in order to observe different portions of the spectrum under the same conditions, to vary the angle between the axes of the observing and collimating telescopes by the rotation of the arm which carries one of these telescopes about an axis parallel to the refracting edge of the prism. Usually the arm which carries the slit and the collimating-lens is fixed, and that carrying the observing telescope is movable; but sometimes the apparatus which it is necessary to carry on the observing arm is so massive, or else requires such a degree of stability, that it becomes necessary to fix it in position and make the slit-arm the movable one. Then difficulties are at once encountered in the illumination of the slit, if a fixed source of light, such as the Sun or a star, is under examination. Even if terrestrial sources be employed, it is ofttimes extremely undesirable to have a complicated system of collimator, slit, condenser, and source of light, swinging about on a long arm, and in particular cases such an arrangement is absolutely inadmissable. In such cases where both arms of the spectroscope are necessarily fixed, we may easily bring the different parts of the spectral field to the cross wires of the observing telescope by a rotation of the prism alone; but in none of the usual forms without violating the usual condition imposed in spectroscopic work, viz., that the prism shall always be in minimum deviation for the central ray in the field.

Heretofore the only forms of "fixed-arm" spectroscopes which

fulfil the latter condition have been of the Littrow type, in which the ray is, by a system of reflecting surfaces, made to traverse the prism twice in opposite directions, and to emerge finally in a direction parallel but reversed in direction to that in which it entered.

The original form and the various modifications of this instrument have been already described.* While they fulfil the condition of bringing any part of the spectral field into the field of the observing telescope without changing the angle between the latter and the collimator, there are certain objections to all of them. The most serious objection to the original form, that of a general illumination of the field, has been simply and successfully overcome in the manner already pointed out by the author,† but the second objection, that of a close proximity of the slit to the observing eyepiece, remains. Young's and Browning's modifications overcome this latter as well as the former difficulty; but they are both complicated and expensive, necessitating as they do the use of at least three reflecting-surfaces and two independent telescopes, in addition to the usual prisms. Moreover, with all instruments of this general type, it is necessary for the beam of light to pass twice through the prism or train of prisms, and this where brightness is of more importance than large dispersion, as with very faint sources of light for example, is a disadvantage. For these reasons I have thought it would be of interest to describe some simpler forms of "fixed-arm" spectroscopes, which I have recently devised and used, and in which the usual arrangement of parts may be preserved, viz., a separate collimating and observing telescope, on opposite sides of a prism-train, through which train the light is passed but once. The slit and observing eyepiece are thus far removed from each other, and the axes of the observing and collimating telescopes may be arranged to make any fixed angle with each other.

The general solution of the problem is effected by the introduction into some part of the spectroscopic train, between the slit and the focal plane of the observing lens, of a reflecting surface, which has an angular motion equal to one-half the change in angular motion of the ray refracted at minimum deviation. In the instruments of the Littrow type a reflector is also used, but for an essentially different purpose (to return the ray through the prism) and in an essentially different way from that here indi-

* "An Improved Form of Littrow Spectroscope," F. L. O. Wadsworth, *Phil. Mag.*, July 1894.

† Ibid.

cated. It hardly seems possible that the use of a reflecting surface in this way can be new, as it is something which would naturally suggest itself to anyone who might consider the problem; but no reference has been found to its employment, perhaps because the necessity for a "fixed-arm" spectroscope does not often seemingly arise. I hope to show, however, that at least some of the forms which have been developed during the last three years are simpler, more convenient, and less expensive than the ordinary form, and for spectrometric work quite as accurate. I will briefly describe these forms in the order of design and use, for this, perhaps, naturally is also the order of increasing simplicity.

Case I.—The case which first led me to a consideration of the problem was one in which it was desired to examine the radiations from a Geissler tube by means of the wave-comparer.* Here the instrument which took the place of the usual observing eyepiece was a massive apparatus weighing about 500 pounds, which required great steadiness of mounting, while the Geissler tube, which itself served as the slit, was attached to a mercury-pump on one side and to a sodium-amalgam generating apparatus, with its attached drying-tubes, mercury-valves, etc., on the other, in such a way as to make its movement impossible. At first, indeed, the tube was mounted on a slit-arm of the spectroscope, sufficient flexibility being secured to allow of different lines being brought on the slit of the wave-comparer by the use of long lengths of glass tubing, but experiments soon showed that it was necessary to keep the passage from this Geissler tube to the pump as short and large as possible. If any considerable length of tubing intervened, unusual precautions had to be taken to keep all parts of it *perfectly* dry and clean, for only under these conditions, which, as the tubes were frequently changed, were almost impossible to maintain, could the McLeod gauge attached to the pump be relied upon to give, even approximately, the true pressure in the tubes, particularly when the electric discharge was passing.

The arrangement adopted in this case was that shown in plan in fig. 1, Pl. XLIII; where *t* is the Geissler tube which serves as the source; *m* a mirror, mounted on a vertical axis on the movable spectroscopic arm R; and S the slit of the wave-comparer, which separates out the radiation which is to be analysed by the latter. To the lower end of the shaft which carries the mirror *m* is fixed a drum connected with a second drum *a*, fixed on the axis of the spectroscope by two steel cords. The drum *a* is just one half the

* See a paper by Professor A. A. Michelson, "Application of Interference Methods to Spectroscopic Measurements," *Phil. Mag.*, Sept. 1892.

size of b, and hence, as the arm R revolves about the axis of the spectroscope, the mirror m revolves on its own axis with an angular velocity just one half that of the arm, but in the opposite direction. Hence, if the mirror is once adjusted so that the direction of the reflected ray is parallel to the axis of collimation, it will remain parallel to that axis for all positions of the arm, and we have therefore a virtual rotation of the slit. There will be a slight lateral displacement of the ray, which can be easily investigated.

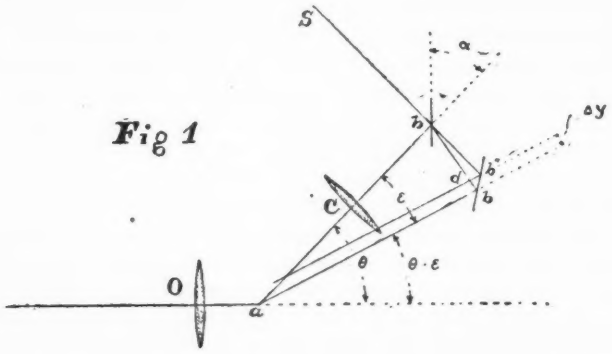


Fig 1

For a certain position of the arm, say $a\,b$, Fig. 1, the reflected ray $b\,a$ will lie in the principal axis of the collimating lens, which we will suppose passes through the centre of rotation of the mirror m. Let θ be the angle of deviation for this position, then for any other position of the system in which the deviation is $\theta \pm \varepsilon$, the reflected ray will be parallel to the axis of collimation, but will be displaced laterally from it a distance Δy. Finally, let α be the angle between the mirror-face and the axis of collimation in the position $a\,b$, then, from the construction of the apparatus, this angle for any position $b'\,a$ will be $\alpha \mp \varepsilon/2$. From the two small triangles $b'\,b''\,d$ and $b\,b'\,b''$ we get at once

$$\Delta y = b'\,b'' \cos(\alpha - \varepsilon/2) = 2r \sin\frac{\varepsilon}{2} \cos\left(\frac{\varepsilon}{2} + 2\alpha\right),$$

where r is the distance between the spectroscope axis and the mirror axis. If ε be small this expression is a minimum for $\alpha = 45°$, when the angle between the incident and reflected rays on m is a right angle. Under the conditions

$$\Delta y = -2r \sin^2\frac{\varepsilon}{2},$$

the angular error in the reading will evidently be

$$\delta = \frac{\Delta y}{R} = -\frac{2r}{R}\sin^2\frac{\varepsilon}{2}. \quad . \quad . \quad . \quad (1)$$

where R is the focal length of the collimator. For most prisms ε will not exceed 6° from end to end of the spectrum, and hence, if we suppose $\alpha = 45°$, for the position of mean deviation we have for the maximum error $\delta = .0013r/R$, or if $r/R = \frac{1}{10}$, $\delta = 25''$.

It is evident that there will be a change in the focal distance S, *b*, C as the arm revolves, which under the conditions just assumed, would amount to about $\frac{1}{200}$ R. This was not altogether a disadvantage, for when the lenses O and C are either or both of them simple lenses, we can, by choosing a value of r/R suitable to the particular prism used, very nearly compensate for the optical change in focus in passing from the violet to the red, or *vice versa*, by the mechanical lengthening or shortening of the path S*b*C. From an inspection of (1) it will be seen that the correction will diminish as the ratio r/R diminishes, and will become 0 for $r = 0$, or for $R = \infty$. This indicated at once two methods of eliminating the error. The first and simplest is to place the mirror between the prism and collimator instead of between tube and collimator as indicated in dotted lines in Fig. 1 (Pl. XLIII). The second is to make $r = 0$ by placing the mirror-face in the axis of rotation of the spectroscope. To do this we must either place the prism considerably out of center, Fig. 2 (Pl. XLIII), or else we must place the mirror above or below the plane of refraction (Fig. 3, Pl. XLIII.) In either case a second reflector must be used to receive the beam from the first reflector *m* and return it to the prism. This second reflector may conveniently be a concave mirror of a focal length *sm* + *mc*, which will at the same time serve as collimator, or as an objective of the observing-telescope. As the motion of the mirror is in this case the same in direction as that which must be imparted to the prism in order to keep it in minimum deviation, the mirror may be attached directly to the prism-table or to the prism itself.* Which of these two latter forms is to be used will be determined by the conditions of use. The second form was the one employed when the wave-comparer was used in connection with a spectrometer in experiments on wave-length measurements in the infra-red solar spectrum. In this form the ray is reflected out of the plane of incidence and refraction, and the spectrum is consequently inclined at a small

* The back of the prism may be polished and silvered, and arranged to act as the first reflector, as in Fig. 2*b*, Pl. XLIII.

angle to the horizontal, but in this case this was of no disadvantage, as it involved only a slight rotation of the observing-slit in order to bring it parallel to the spectral lines.

Case II.—In the forms so far considered, no special conditions were imposed other than the general conditions of a fixed slit and a fixed observing instrument, it being possible to move the latter to meet the requirements of the particular optical systems which have been described. But in the next application of this system to the great spectro-bolometer of the Astro-physical Observatory, an instrument in which the collimator has a focal length of nearly thirty feet, and the observing telescope a focal length of nearly twelve feet, another condition was imposed, viz., that the observing instrument (in this case the bolometer) should be in the prolongation of the axis of collimation. It was therefore necessary to avoid the lifting of the spectrum above the plane of incidence and refraction, and to place the mirror *m* at one side of the prism at such an angle to the latter that the direction of the reflected ray was parallel to the line of collimation as required. This throws the mirror-face out of the axis of rotation, and there is therefore a lateral displacement of the ray as the system rotates. A plan view of this arrangement is shown in Fig 2. It will be seen that the arrangement of parts

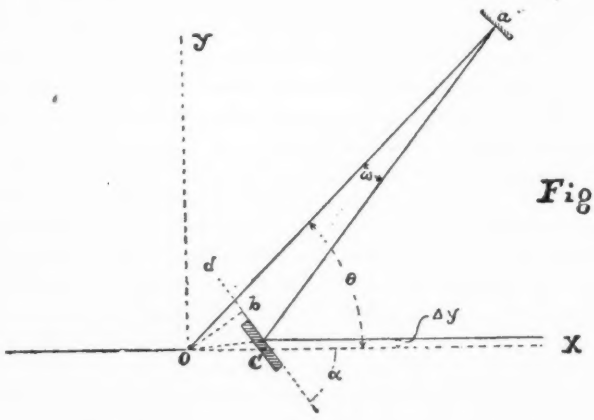


Fig 2.

is essentially that employed in the first case described, except that a concave mirror is now used instead of the lens. The calculation of the lateral displacement, although not quite so simple as in the first case, is easy.

In Fig. 2,

let d = distance oa from axis of rotation to the face of the concave mirror;

r = perpendicular distance ob from the axis to the plane of the reflecting mirror;

ω = angle oac;

θ and α have the same meanings as before.

When in adjustment the line of collimation passes through the axis of the rotation, and the deflected ray oa will fall on the center of the concave mirror. Then we have from analytical geometry the following equations:—

For the line ac,

$$y = \tan(\theta + \omega)[\chi - d\cos\theta] + d\sin\theta$$
$$= -\tan 2\alpha\,[\chi - d\cos\theta] + d\sin\theta, \quad . \quad . \quad (2)$$

since $\theta + \omega = 180° - 2\alpha$;

and for the line dc,

$$y = -\tan\alpha\,(\chi) + \frac{r}{\cos\alpha}. \quad . \quad . \quad . \quad (3)$$

The lateral displacement (Δy) of the ray will be the ordinate of the point of intersection of these two lines. Solving (2) and (3) for y we have

$$\Delta y = d\sin(2\alpha + \theta) - 2r\cos\alpha.$$

If the system be turned through a small angle ε, θ becomes $\theta + \varepsilon$, and α becomes $\alpha - \varepsilon/2$. Hence $\theta + 2\alpha = \text{const.}$, and

$$\Delta y' = d\sin(\theta + 2\alpha) - 2r\cos(\alpha - \varepsilon/2),$$
$$\Delta y - \Delta y' = 2r[\cos\alpha - \cos(\alpha - \varepsilon/2)] \cong r\cos(\theta + \omega)\sin\varepsilon;$$

or the lateral displacement is directly proportional to r, to the cosine of the angle of deviation, and to the angle of displacement. Since ε is fixed by the prism used, and ω must be small in order to secure good definition, the only way in which the error of displacement may be reduced is by reducing r; hence the object in placing the mirror just as close to the prism as possible. In the actual case, the values of r, θ, and ω were

$$r \cong 10 \text{ centim.}, \ \theta \cong 50° \text{ (for D lines)}, \text{ and } \omega \cong 3°.$$

Hence for $\varepsilon = 3°$ we have $\Delta y' = 3$ millim., and the angular error is, as before, $3/R = \frac{3}{3560} = 3'$ nearly.

It will readily be seen that if we do not impose the condition that the reflected ray shall be parallel to the line of collimation,

we may place the mirror so that the displacement will be almost *nil* for even very considerable values of r. This general case may be readily worked out by introducing into the above another angle, β, which is the angle between the axis of collimation and the ray reflected from the mirror, connected with the angle θ and α by the relation

$$\theta + \omega = 180 - (2a + \beta).$$

In this case it will be found, as might have been expected, that the displacement is a minimum when the angle α is as nearly as possible equal to θ, viz., when the angle of incidence on the mirror is as nearly as possible 90°. In the most unfavorable case, however, the correction, although considerable, is not of sufficient magnitude to become objectionable in spectroscopic work. In such work it is not even necessary to apply the correction, as the effect is the same as would be produced by a slight change in the optical properties of the prism. The displacement might in this, as in the former case, have been eliminated by making $R = \infty$, viz., by substituting for the concave mirror at a a plane reflector and placing the image-forming objective beyond the reflecting surface m; but the additional reflecting surface was objectionable as diminishing the brightness of the spectrum.

Case III.—The arrangement last described was used with a considerable degree of success for some time, but when some very accurate angular measurements were attempted with it a difficulty of a mechanical character presented itself. It will be noted that the correct working of this—as of all systems so far described—depends on the maintenance of an exact ratio of 2 to 1 between the angular motions of the spectroscope-arm and of the reflecting mirror. It is necessary to maintain the prism at minimum deviation in all spectrometric measurements; but not with any great degree of exactness, as an error of 2′ or 3′ in the angular position of the prism will not affect the deviation by more than $\frac{1}{50}$ of this amount. But with the mirror any error in angular position with respect to the arm will change the angular direction of the refracted and reflected ray by double that amount; and hence if we wish to determine any angle of deviation to within 10″, we must be sure of the position of the mirror to within less than 5″. To secure this degree of accuracy mechanically and automatically with any ordinary minimum deviation attachment is out of the question, for an error of 5″ in angular position means in linear measurement an error of only $\frac{1}{1000}$ millim. at the end of an arm 40 millim. long. Probably this degree

of accuracy could be secured if necessary by the use of a minimum deviation attachment of pure linkwork, like that shown in Fig. 4 (Pl. XLIV), which is far superior in every respect to the ordinary sliding link-form usually placed on a spectroscope.* It may also be secured by the system first described, because in it any required degree of accuracy may be reached by an increase in size of the drums, *a*, *b*.

It was at first thought that a return to this system would be necessary; but while considering how this could best be done, the idea of another simple system, which did away with all mechanical arrangements, presented itself. It is derived from the first modification of the earlier system (Fig. 1, Pl. XLIII) very easily by suppressing entirely the movable spectroscope-arm and securing the reflecting mirror rigidly to the prism. It will evidently have the same angular motion as before, and will therefore reflect a ray which passes through the prism at minimum deviation in the same direction for all positions of the latter, or *vice versa*. With this arrangement it is evident that there will be no error due to mechanical inaccuracies of the moving parts because there is no longer any relative motion between them, both prism and mirror being fixed relatively to each other. But it would appear at first sight that for large angles of deviation the light would fall upon a very different part of the reflecting mirror to that which it would for small angles, and that a large lateral displacement of the reflected ray might be expected in consequence. The lateral shifting is no great detriment if a collimator is used, and the beam which passes through the prism is a strictly parallel one, for then its effect is simply to necessitate the loss of some light, or else the use of larger lenses to provide for this shifting. But where only one objective is used, as in the simpler forms of instruments, or for some special reason in the better ones† (see Fig. 7, Pl. XLIV), and the beam through the prism is in consequence conical, the lateral displacement gives rise, as already explained, to an angular error depending on the radius of curvature of the wave-front of the incident beam. This error, or, more properly, correction, was especially objectionable in the particular work then in hand, in which it was very desirable to maintain an exact relationship between the angular reading of the spectrometer-circle (in which prism and mirror were mounted), and the wave-length of the radiation falling on what corresponded to the

* Kempe, 'Lecture on Linkages,' p. 40.

† In this case it was desirable in order that there might be as little loss by reflection and absorption as possible.

cross-wire of the observing telescope. On examination of the geometrical path of the ray through the system just indicated, it was unexpectedly found that if two simple conditions were fulfilled, the refracted ray was, after reflection, not only constant in direction but also constant in position, viz., that there was no lateral displacement for different wave-lengths, and consequently no angular correction required for either plane or spherical waves. To find these necessary conditions, let us first consider the general case in which the axis of rotation and the reflecting-mirror are in any position with reference to the line of collimation.

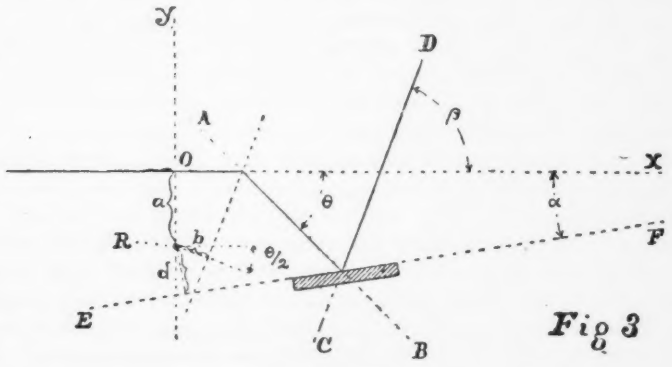


Fig 3

Let the axis of collimation be the X axis, and let a line passing through the axis of rotation R be the Y axis. Let d be the perpendicular distance from the axis of rotation to the plane of the mirror-face; let b be the perpendicular distance from the same point to the plane bisecting the angle of the prism (and hence bisecting also the angle of deviation of the ray at minimum deviation), and let a be the y coördinate of this point. Then the equation of the line EF (the intersection of the plane of the reflecting surface with the XY plane) will be

$$y = \tan \alpha x - \frac{d + a \cos \alpha}{\cos \alpha};$$

and of the line AB (refracted ray),

$$y = -\tan \theta \chi + \frac{2 \sin \theta/2}{\cos \theta} \{\sin \theta/2 + b\}.$$

The coördinates of the points of intersection of these two lines will therefore be

XUM

XUM

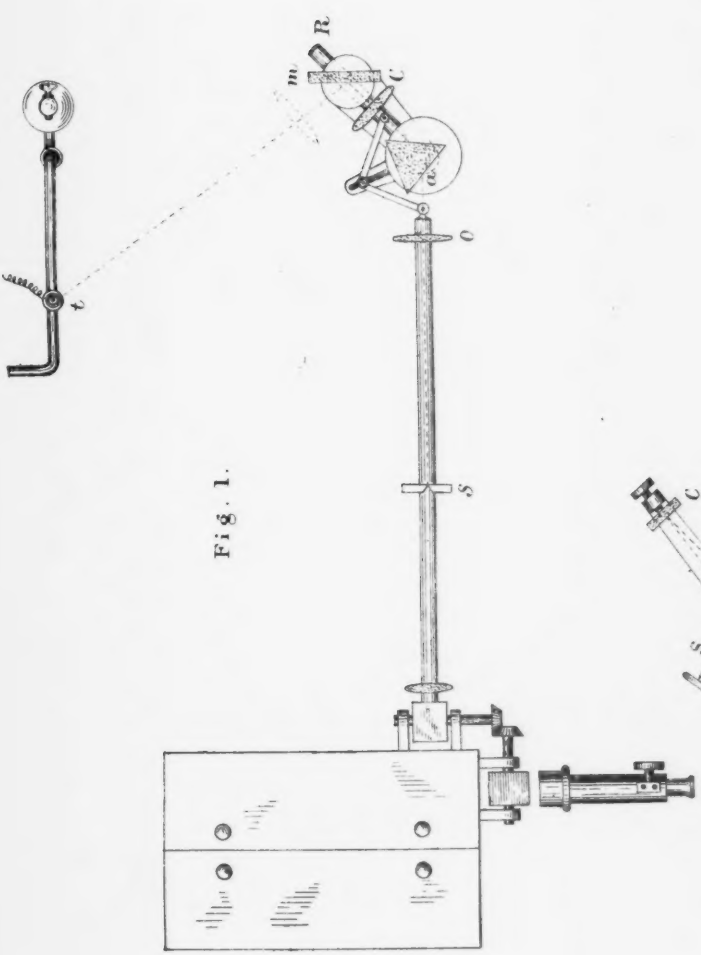


Fig. 1.

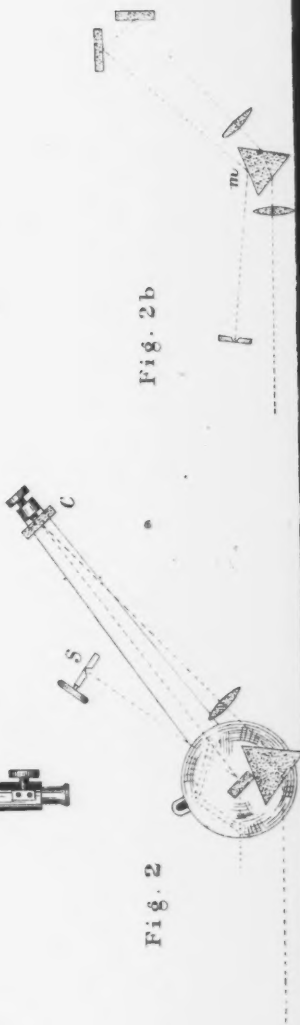


Fig. 2b

Fig. 2

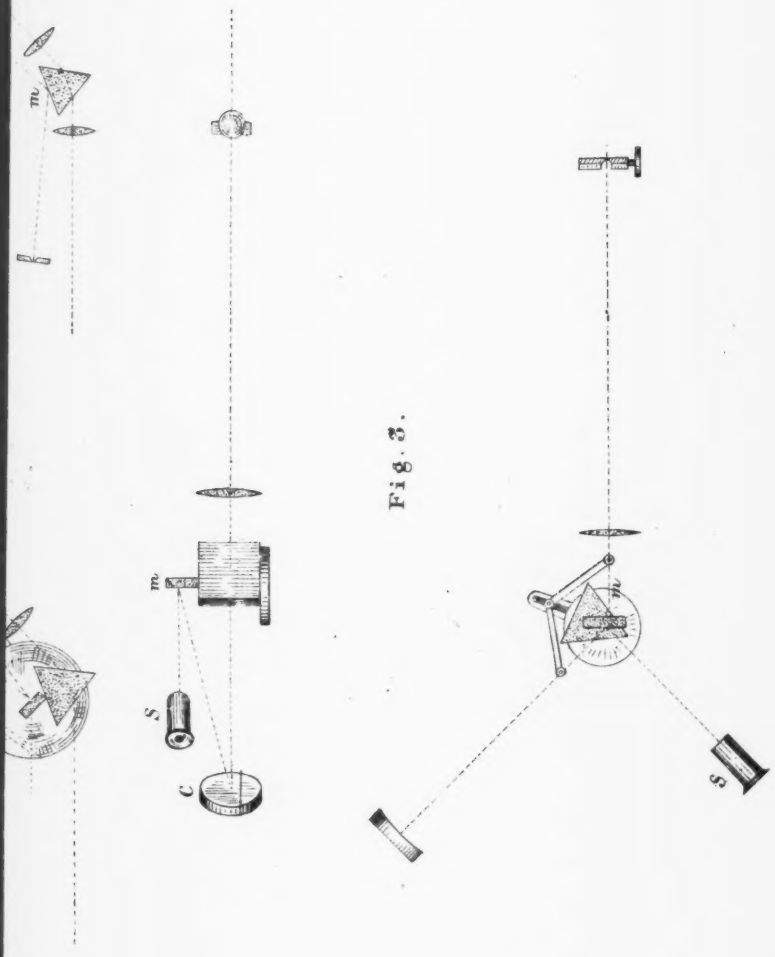
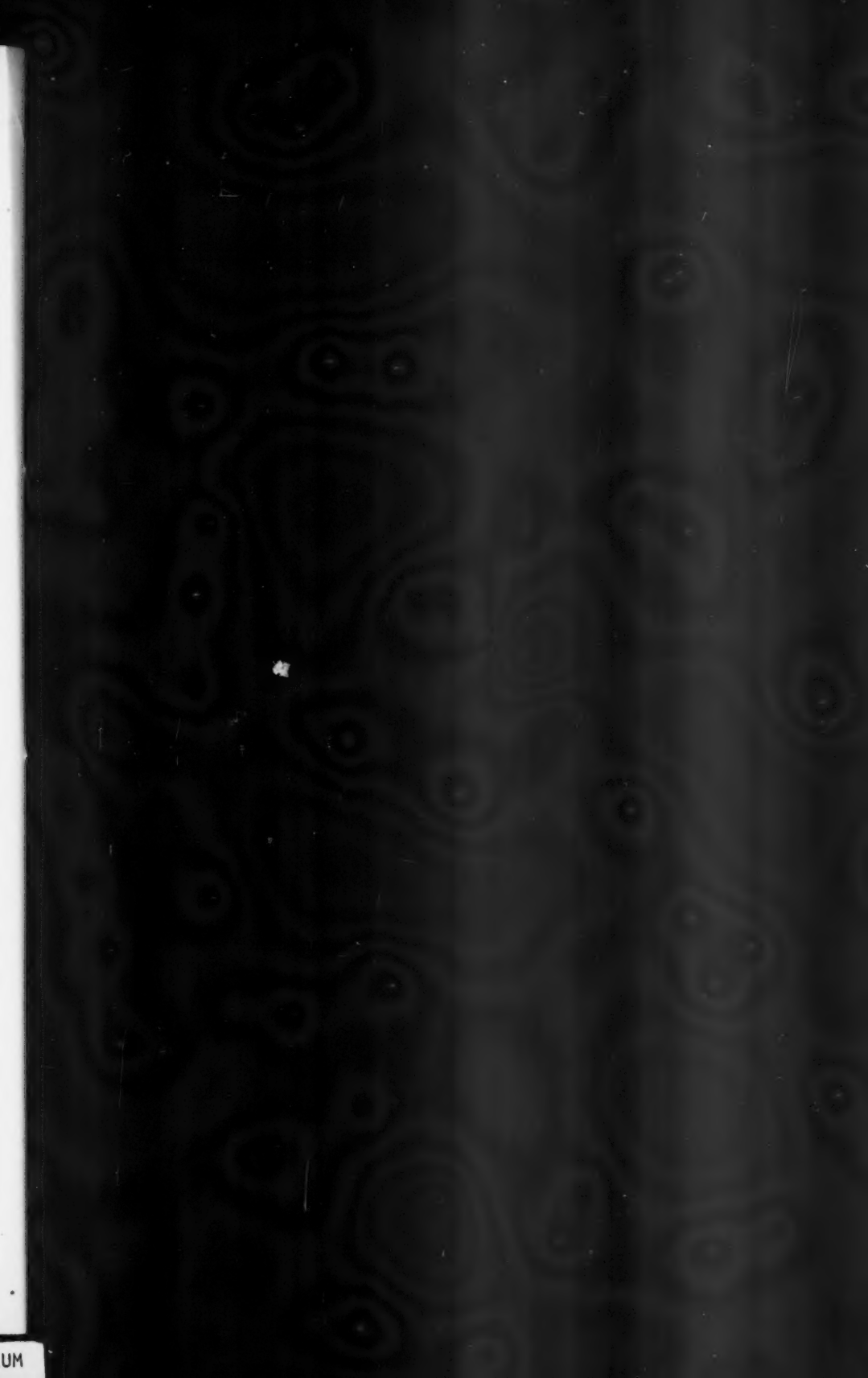
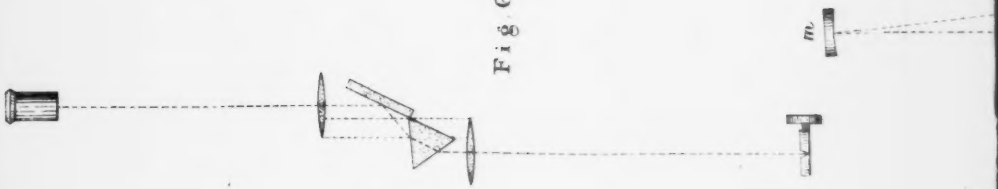


Fig. 3.



XUM

Fig 6.



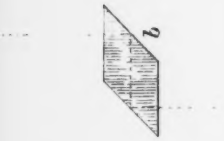
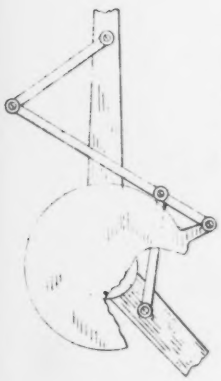
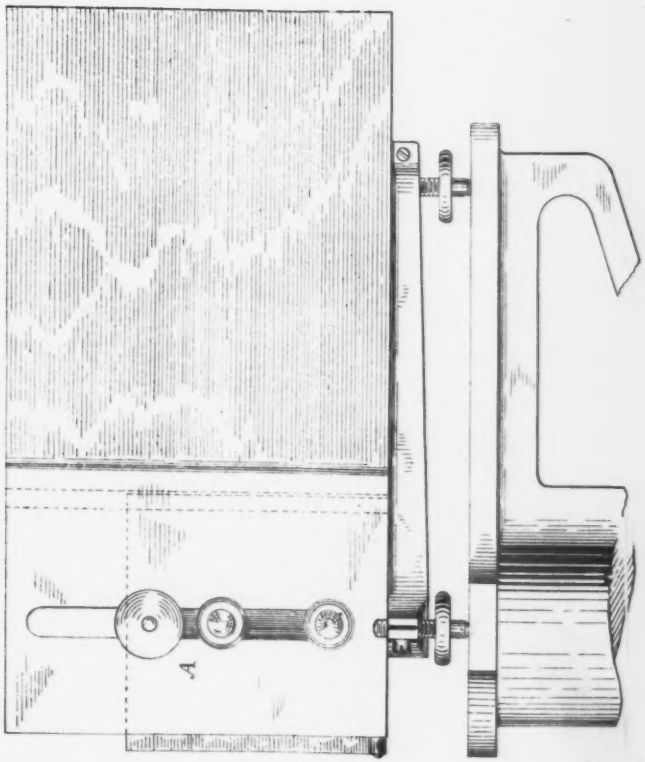


Fig 4





V.

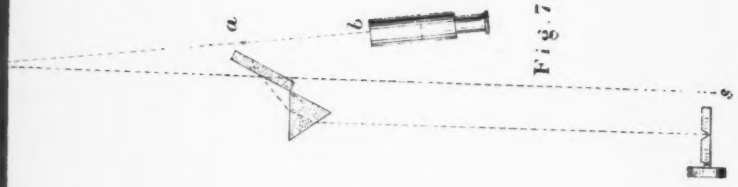
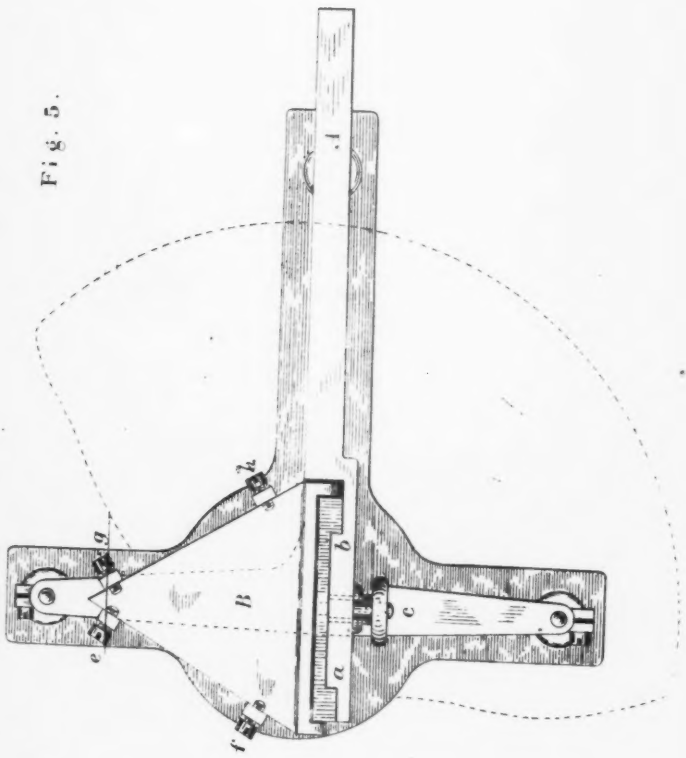


Fig. 7.

Fig. 5.



cs, No. 130.

XUM

$$x' = \frac{\frac{2\sin\theta/2}{\cos\theta}[a\sin\theta/2 + b] - \frac{d + a\cos\alpha}{\cos\alpha}}{\tan\alpha + \tan\theta},$$

$$= \frac{2\sin\theta/2\cos\alpha\,[a\sin\theta/2 + b] - (d + a\cos\alpha)\cos\theta}{\sin(\alpha + \theta)},$$

$$y' = \frac{2\sin\theta/2\,[a\sin\theta/2 + b]\tan\alpha - \frac{d + a\cos\alpha}{\cos\alpha}\tan\theta}{\tan\alpha + \tan\theta}$$

$$= \frac{2\sin\theta/2\sin\alpha\,[a\sin\theta/2 + b] - (d + a\cos\alpha)\sin\theta}{\sin(\alpha + \theta)}.$$

The equation of the reflected ray CD will be

$$y - y' = \tan(\theta + 2\alpha)(x - x'),$$

and the length of the perpendicular let fall from the origin will be

$$p = \frac{\tan(\theta + 2\alpha)\,x' - y'}{\sqrt{1 + \tan^2(\theta + 2\alpha)}} = x'\sin(\theta + 2\alpha) - y'\cos(\theta + 2\alpha).$$

Substituting the values of x' and y', reducing, and introducing the relations

$$\theta + 2\alpha = \beta = \text{constant},$$
$$\theta + \alpha = (\beta - \alpha).$$

we finally obtain

$$p = 2a\cos^2\beta/2 + 2b\sin\theta/2 + 2d\cos(\alpha + \theta).$$

The term $2a\cos^2\beta/2$ is a constant, but the last two terms are variable. It will be seen at once that we may make p a constant, viz., prevent any lateral shifting of the ray, by simply making both b and d equal to zero. In other words, if we simply fulfil the condition that the axis of rotation of the system shall be at the intersection of the plane bisecting the refracting angle of the prism with the plane of the reflecting mirror, there will be no lateral displacement of the ray which passes through the system at minimum deviation, for different values of θ, viz., for different wave-lengths. There is one case in which this does not hold, viz. when these two planes are parallel. Then we have

$$\alpha = 90° - \theta/2, \text{ or } \alpha + \theta = 180° - \alpha.$$

Hence

$$b\sin\theta/2 + d\cos(\alpha + \theta) = (b - d)\cos\alpha;$$

and therefore we may in this case make p constant by making $b = d$: in other words, by making the two planes coincident. Then the second half of the prism becomes useless, and we have

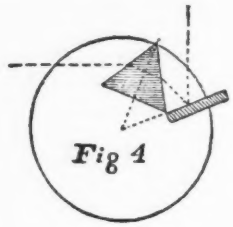
the original half-prism form of Littrow, Fig. 5, which is now seen to be only one special form of a general class. It is evident that by varying the angle α we may make the angle β anything we please from 0 to 360°. Four special cases only are considered:

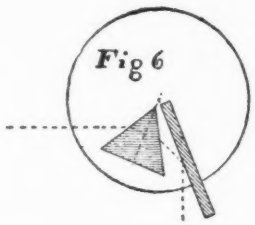
(1) When $\beta = 90°$, then for $\theta = 45°$ we have $\alpha = 22\frac{1}{2}°$. The arrangement of the parts is shown in Fig. 4.

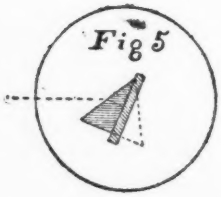
(2) When $\beta = 180°$, $\alpha = \frac{1}{2}\theta$, and we have the Littrow half-prism arrangement already referred to (Fig. 5).

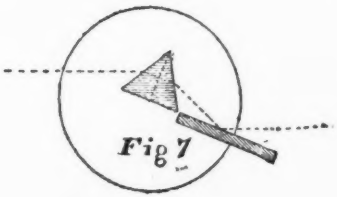
(3) When $\beta = 270°$, for $\theta = 45°$, $\alpha = 112\frac{1}{2}°$, and we have the arrangement shown in Fig. 6.

(4) Finally, when $\beta = 0$ the reflected ray is parallel to the coincident, and now $\alpha = -\theta/2$ (Fig. 7).









In all these last forms the prism-mirror system is mounted directly on the graduated circle of the spectrometer and revolves with it. Since the angular rotation of the prism is exactly one-half that of the refracted ray which passes through it at minimum deviation, it follows that we may determine angular deviations from the readings of the spectrometer circle, just as in the ordinary forms of the instrument, except that the angular readings must be multiplied by 2 to obtain the angular deviations. The movable parts of the instrument (the mirror and prism) are therefore rendered extremely light and mobile, without any sacrifice in accuracy, while incidentally the more or less troublesome minimum-deviation attachment is done away with. The last

arrangement, which is in one sense a direct-vision spectroscope with but a single prism, fulfils the condition of parallelism between the refracted reflected ray and the incident ray, and it is therefore the one which has been finally adopted for the spectro-bolometer of the Observatory in place of the form first used on that instrument.*

A plan view of the mounting in this particular form of instrument is shown in Fig. 5, Pl. XLIV, and a side view (photograph) in Pl. XLV. It will be seen that the prism and mirror are mounted together in a single frame AA, provided with three leveling-screws which rest, one in a conical hole, the second in a slot, and the third on a plane; so that the whole frame may readily be removed from the spectrometer table and then replaced in exactly the same position. The triangular prism-table B is arranged to slide vertically in the guides *a b*, and thus provide for prisms of different heights. The table has a motion of adjustment regulated by the screw *c*, about a line parallel to the mirror-face, for the purpose of bringing the refracting edge of the prism parallel to that face, and is provided with screws *e*, *f*, *g*, *h*, which serve to adjust the prism laterally and in angle, so that in the first place the plane bisecting the refracting angle may pass through the axis of rotation, and secondly, so that the prism-faces may make equal angles with the faces of the mirror (the minimum-deviation condition.) It will be observed that when these screws are once adjusted they serve as stops which will bring any prism (of standard 60° angle) that may be used into the correct position; for, if smaller than the prism for which they were adjusted, it is only necessary either to turn each one in a measured amount, or, more simply, insert a thin piece of glass or metal between the screws on each side and the prism. A still better plan, if many prisms are to be used, is to have each prism mounted on a base of the required size on which it has been adjusted once for all and

* Since writing the above my attention has been called to an article in *Zeit. fur Instrumentenkunde* for November, 1881, describing this particular "direct-vision" arrangement of the prism and mirror. There was, however, no indication of the general class of which this is but a particular type, and hence, of course, no indication of the conditions which it was necessary to fulfil to prevent a lateral shifting of the beam; indeed, the author seems to accept this lateral shifting as a necessary condition, for he says "Der im Minimum der Ablenkung durchgehende Strahl wird also bei dieser Anordnung nur seitlich etwas verschoben."

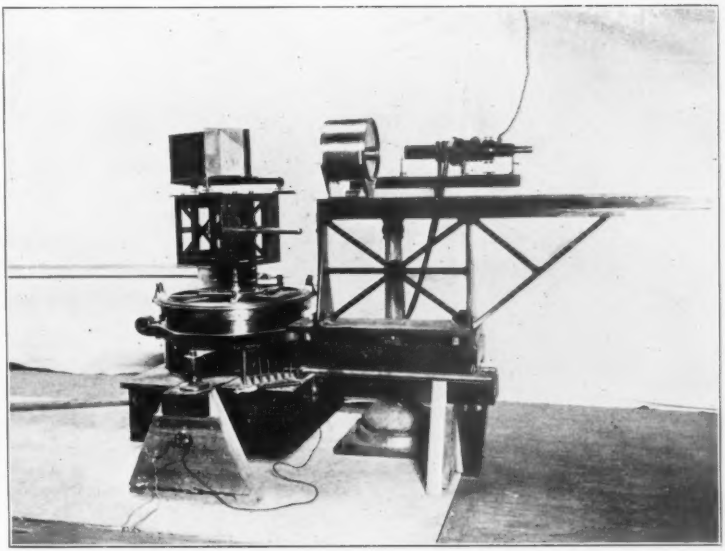
Professor Langley had also quite independently used this particular arrangement of prism and reflecting mirror in a modification of Foucault's "Lifting Prism" for separating different orders of superposed grating-spectra. In his use of it the lateral displacement was recognized as objectionable, and was mechanically corrected for by an ingenious arrangement, designed by Mr. C. T. Child, then assistant in the Observatory, which imparted to the mirror a small angular motion, just sufficient to correct for the angular displacement of the spectral image, as the whole system travelled down through the spectrum.

then cemented. The adjustment, as will be shown hereafter, does not need to be particularly accurate.

The mirror and prism having been adjusted to each other and to the spectrometer axis once for all, the other adjustments preliminary to the use of the instrument are very simple. The first operation is to make the axes of the collimating and observing telescopes parallel. This is most simply done by removing the prism-mirror system and allowing the beam for the collimator to fall directly on the objective of the view-telescope. Since the constant lateral displacement of the beam by the system will be $2a$, it follows that if the aperture of the telescope is, say, $2\frac{1}{2}a$, sufficient light will fall upon the second objective to form a distinct image of the slit. Since, however, the use of such a small portion of the objective is apt to cause a lateral shifting of the image, it is better either to mount the view-telescope on a short cross slide, or on a rocking arm, the motion of which is accurately rectilinear, or, what is better, to use a small double-reflection prism, fig. 6*b* (Pl. XLIV), which will laterally deflect the beam by the amount required. If a system like that in fig. 7 (Pl. XLIV) is used the simplest method of initially setting the direct image on the cross wire of the observing telescope is to set up at the side of the slit and at an accurately measured distance $2a$ from its center, a second slit or fine point, and bring the image of this to the center of the field.

The second step is to determine the zero of graduation, which is done by replacing the optical system and revolving the mirror until it is perpendicular to the line of collimation. With the first form of instrument this is accomplished simply by bringing the image of the slit into coincidence with the slit itself; in the second form it is most conveniently done by setting up a point at a distance from the mirror equal to the principal focal distance, bringing this point into the line *b m s* by removing the eyepiece and sighting with the eye past the cross wire at the distant point *s*, and then revolving the mirror until the image of this illuminated point coincides with the point itself. The reading of the circle corresponding to this position of the mirror is called the zero reading. The prism is then replaced in position by being brought against the screws *e*, *f*, *g*, *h*, and the whole system revolved until the desired part of the spectral field is brought into the observing eyepiece. If the spectrum is now either too high or too low, it shows that the refracting edge of the prism is slightly inclined to the mirror-face, and the screw *c* is turned until the spectrum is centered. Then, if all the preliminary adjustments have been properly made, the angular deviation of the central ray in the field will be given by the relation

PLATE XLV.



$$\theta = 2\,(\beta - (90^\circ + \alpha)),$$

where β is the circle-reading for a deviation θ, and α is the zero-reading determined as already described.

In very accurate spectrometric work it is important to determine just what degree of accuracy is required in making the various adjustments of parts to each other in order to attain a given degree of accuracy in the final result. The theory of these adjustments is comparatively simple, but somewhat lengthy, and it will therefore be briefly indicated in a future paper.

ASTRO-PHYSICAL OBSERVATORY, Washington, D. C.,
March, 1893.

ON BRESTER'S VIEWS AS TO THE TRANQUILLITY OF THE SOLAR ATMOSPHERE.

A. BRESTER, JR.

If the views attributed to me by Dr. E. von Oppolzer under this title in the August number of this journal were really mine, his criticism would have been entirely just. But fortunately my ideas are quite different from those attributed to me by Dr. von Oppolzer, and in certain cases they are diametrically opposed to them. For example, Dr. von Oppolzer states twice that in order to bring my theory into agreement with observation I am forced to adopt the impossible hypothesis of a flattened photosphere surrounded by a spherical atmosphere. But this is exactly the reverse of my supposition. My theory requires a *spherical photosphere* surrounded by a *flattened atmosphere*, such as is figured on page 42 of my *Thèorie*.* Such forms have frequently been photographed during eclipses, and described by J. Herschel, Secchi, Lockyer and Young.†

Dr. von Oppolzer has moreover failed to properly understand what my theory indicates to be the principal cause of the tran-

* *Theorie du Soleil. Verhandelingen der K. Akademie von Wetenschappen. Amsterdam* (*Erste Sectie*) *Deel* I, No. 3.

† See, for example, the beautiful photographs made by Whipple in 1869, by Dietrich on Dec. 12, 1871, and by Barnard during the eclipse of Jan. 1, 1889. Secchi, Young and Lockyer also agree in considering that the solar atmosphere has a flattened form: Secchi, *le Soleil*, II, p. 482; I, p. 391. "The Sun is surrounded by a very extensive atmosphere, the height of which is at least equal to half the solar radius. It is more extensive at the equator than at the poles." Young, *The Sun*, p. 173. Lockyer, *Chemistry of the Sun*, p. 424; *ibid*, p. 428, "We have seen that the atmosphere of the Sun over the equator is higher than it is over the poles." *Solar Physics*, p. 49, "Sir John Herschel's beautiful theory, that the Sun is actually colder at the poles, by reason of the smaller thickness of the atmosphere in the polar regions allowing a greater radiation of heat."

quillity of the solar atmosphere. This cause is not, as he seems to suppose, the absence of all external causes of motion. The principal cause of the tranquillity of the solar atmosphere exists in the dissociated and vaporized state of this atmosphere. The atmosphere being necessarily rich in dissociated and vaporized matter ready to condense, and to produce thus new heat in proportion as the existing heat is lost by radiation, a sudden fall of temperature is impossible in it; so *a fortiori* is an unequal fall of temperature, which alone could set the mass in motion. Just as steam in losing heat cannot cool below 100° as long as the whole mass has not been converted into water, so no incandescent vapor can fall in temperature as long as some of the molecules condensable at this temperature remain uncondensed. Thus if the gaseous and vaporous mixture, which forms the solar atmosphere, has not yet reached this condition, its internal calm is not at all surprising.

As this cause of the immobility of the solar atmosphere cannot exist in the terrestrial atmosphere, all of Dr. von Oppolzer's reasoning with the intent to prove that our atmosphere would continue to be disturbed if the Sun did not exist, (or if the Sun could warm us in a uniform manner), has little bearing on my theory.

The solar atmosphere is always filled with saturated vapors, and these vapors bear constant witness to their state of saturation by the fog of condensed particles which, forming the photospheric clouds, is also visible during eclipses in the white prominences and throughout the entire solar atmosphere. In such a saturated fog the temperature will remain stationary, even if great quantities of heat are developed in or abstracted from it.* It is clear that if the solar atmosphere can experience no sudden fall in temperature, a rise in temperature is equally impossible, for any increased heat would be immediately absorbed by the vaporization or dissociation of matter already condensed.

If as a consequence the study of all of the various solar phenomena as well as the phenomena presented by the red variable stars† has led us to the hypothesis of a relatively tranquil Sun, in which the temperature at any point depends only upon its position with respect to the center and to the surface of the mass, I do not see that the arguments of Dr. von Oppolzer should cause

* It is true that the temperature would vary a little if the condensation could cause a marked change of pressure. But when the fog condenses somewhat in a solar "layer," the matter condensed forms such an extremely small fraction of the entire mass that no sensible change in the total pressure can result from it.

† *Theorie du Soleil*, pp. 30-32, 38-40.

us to change our ideas. For we see in the physical and chemical condensations, by means of which the Sun continually restores its lost heat, an automatic brake preventing all movements, which without it would certainly be caused by the cooling due to radiation.

Nevertheless, the tranquillity of the solar vapors is by no means absolute, and it is clear in any case that at those points where the uneven surface of the photosphere with its zones of abnormal velocity meets the base of the exterior solar gases, the tranquillity of the base of the atmosphere will be seriously disturbed. But as the horizontal movements thus caused take place without change of temperature, they remain localized at the level in which they have their birth, and consequently disturb the solar gases only in the immediate neighborhood of the surface of the photosphere.* It will be seen that here my ideas, though arrived at very differently, lead to nearly the same result as those of Dr. von Oppolzer himself. He also reaches the conclusion that the solar gases are permanently stratified, and that, vertical currents being almost impossible, movement takes place most commonly in a horizontal direction, and is of no effect in disturbing the stratification of the overlying gases.†

I would accept without reserve the unexpected support which the analytical investigations of Dr. von Oppolzer seem to give to my theory of the permanent stratification of the solar gases, if these investigations were not based on the hypothesis of an infinitely small density of the solar atmosphere, even at the photospheric level.‡

This is an hypothesis which I cannot omit, and I have devoted 28 pages of my *Thèorie* to its refutation.§ I will not recall here the numerous arguments which are brought together there, but I will now point out two others, unknown to me when developing my theory. These are: 1st, the researches of Professors Vogel and Seeliger on the diminution of the intensity of differently colored

---

* *Theorie du Soleil*, p. 143.

† "If, moreover, we take into consideration (says Dr. von Oppolzer) that the principal movements in an atmosphere take place horizontally, it is evident that the vertical disposition of layers can scarcely be subject to great disturbances . . . it is apparent that if the thickness of the strata be over 1″, a vertical movement can take place only with difficulty, and is in fact almost utterly checked. The expenditure of energy which would thereby be required has been calculated by me in the same paper. Disturbances of the layers in a vertical sense, which would be shown by observations of the spectrum of the chromosphere, can consequently scarcely be seen. . . ."

‡ *von Oppolzer: Ueber die Ursache der Sonnenflecken* (*Sitz. Ber. d. K. Ak. d. Wissenschaften in Wien*, CII., April 1893), p. 5.

§ *Theorie du Soleil*, pp. 87-115.

rays toward the limb of the Sun; according to Dr. von Oppolzer himself, these investigations seem to be in contradiction with the hypothesis of a small photospheric pressure.* 2nd, the observations of M. Deslandres during the eclipse of April 16, 1893. M. Deslandres measured the displacement of the coronal lines in two equatorial regions diametrically opposite to each other, and situated at a distance from the Sun equal to two-thirds of its diameter; he found thus that the corona turns on its axis with the rest of the Sun. The coronal envelope is consequently an immense atmosphere resting upon the surface of the photosphere. It is inconceivable that an atmosphere of such immensity, which is at the same time dense enough to produce measureable lines at a height of 150 terrestrial radii, can have at its base an infinitely small density.

There are still other analogies between the ideas of Dr. von Oppolzer and myself; for example, I also consider that *the spots are radiation phenomena*. I explain the formation of a spot as follows: We will suppose that at a given point in the photosphere the loss of heat by radiation has lasted long enough to cause condensation of the molecules R, which hitherto had prevented the reunion of the molecules A and B. These molecules, A and B, will profit by the occasion to combine, and the heat of combination then produced—which as I have explained above, is incapable of causing a sensible rise in temperature—is entirely absorbed in the vaporization of the previously condensed cloudy matter. This explains how the photospheric clouds are dissolved in the spots, and how in the openings thus produced the temperature is always the same as in the unbroken surface of the photosphere.

According to Dr. von Oppolzer the spots are exceptionally cool gaseous masses, sunk in the photosphere and covered by exceptionally hot gaseous layers. He supports this hypothesis on the bolometric observations of Professors Langley and Frost and the spectroheliographic observations of Professor Hale. But none of these observations, in spite of their interest, can furnish us certain information regarding the temperature of the objects observed. If the spots in general emit less heat than the other parts of the photosphere, it by no means follows that the spots really have a lower temperature. I see here only the very simple effect of a lower emissive power. For at equal temperatures a

* von Oppolzer: *Ueber die Ursache der Sonnenflecken*, p. 17. Vogel: *Monatsber., Berlin*, 1877, p. 104. Seeliger: *Sitzungsber., Menchen*, XXI, Heft 3 (1891).

gas emits less heat than a condensed dust.* And as for the H and K lines, their bright reversal over spots does not prove the existence there of a higher temperature. For we know from the researches of Wiedemann, R. von Helmholtz, W. Siemens and Pringsheim that the light emitted by an incandescent gas does not depend solely upon the temperature, but for the most part upon the chemical combinations which take place in it.† The regions immediately overlying spots should be particularly well suited for the production of chemical combinations and the consequent increase of luminosity. For in virtue of the inferior emissive power of the gas filling the spot, all the neighboring regions of the solar atmosphere will be less highly heated than are those where the incessant loss of heat by radiation is more fully compensated for by the greater radiation of the unbroken photosphere. And as in the solar atmosphere chemical combinations become possible only as the result of heat losses, it is quite natural that such processes should take place above and around spots. In these regions, consequently, and with no possible increase of temperature, chemical luminescence will occur. Its effects will be seen either as bright reversals of the H and K lines,

* It must not be forgotten that the heat rays, which the spots seem to emit, will necessarily be strengthened if the solar atmosphere which they traverse is filled with incandescent dust of high emissive power. Now my theory requires above spots a condensation more abundant than elsewhere of cloudy dust. This dust seems to me to have been frequently observed: in the scintillation which Trouvelot has remarked above the umbra of spots, producing there the effect of flurries of snow; or in the intensely brilliant objects moving with a velocity as great as 33 leagues per second, which Carrington and Hodgson observed for several minutes on the edge of a spot; or as filaments of white matter seen by Secchi to transform rapidly into rose-colored veils; or as white prominences; or even as coronal streamers.—Trouvelot: *Bull. Astr.* Vol. II.—Lockyer: *Chemistry of the Sun*, p. 411.—Carrington: *Monthly Notices*, Nov. 1859.—Young: *The Sun*, p. 93.—Secchi: *le Soleil*, I, p. 104, (Figs. 53, 54, 55).

† E. Wiedemann: *Pogg. Ann.*, (N. F.) 37, pp. 177-248.—R. von Helmholtz: *Die Licht und Warmestrahlung verbrennender Gase*, Berlin, 1890.—E. Pringsheim: *Wied. Ann.* 45, p. 428, *Das Kirchhoffsche Gesetz und die Strahlung der Gase*, *Wied. Ann.* 49, p. 347.—According to Dr. Pringsheim the importance of chemical processes in the production of the light emitted by incandescent gases is so great that without these processes no light whatever would be emitted.—Dr. F. Paschen (*Wied. Ann.* 50, pp. 409-443), while disputing this conclusion of Dr. Pringsheim, is nevertheless forced to admit that chemical processes frequently strengthen luminous emission. We know, moreover, that at a temperature of less than 150° sulphide of carbon produces a bluish flame giving a discontinuous spectrum. It is consequently not true that the luminous emission of an incandescent gas depends only on the temperature, and the common application of Kirchhoff's Law in astro-physics thus loses its security. Let us consider, for example, the bright lines in the spectra of Novæ and of many variable red stars. These lines are not necessarily produced by a gas at a very high temperature. It is much more probable that, in accordance with my theory, they are only the effect of chemical luminescence. In the coolest layers of these comparatively cool stars the molecules A and B combine chemically, and the heat thus produced vaporizes the clouds, and temporarily reveals to us the glowing interior. See in this connection Ebert: *Vierteljahrschrift der Astron. Gesellschaft*, 1892, p. 34. Pringsheim: *Wied. Ann.* 45, p. 428; 49, p. 347.

or as ordinary prominences, which are phenomena of the same class. Both reversals and prominences prove that the dissociated substances in the solar atmosphere are always ready to unite when a sufficient loss of heat renders this possible.

I trust that the present article will serve to demonstrate that my theory has not all the faults pointed out by Dr. von Oppolzer, and that it is in no particular, within my knowledge, in contradiction with observed facts, with the laws of physics and chemistry, or with its own principles. Dr. von Oppolzer has attributed far too much importance to my principle of the immobility of the solar atmosphere.* The fact is that I have never denied the existence of violent atmospheric disturbances; but as my theory maintains that these violent disturbances (as, for example, the movements in spots) take place without marked change of temperature, they must remain localized in the level in which they have their origin. They can cause no ascending current, and consequently they can disturb the surrounding atmosphere only in their immediate vicinity. I maintain the immobility of the solar gases only in the vertical direction, and I have always resolutely denied it in those parts of the solar atmosphere which come in contact with the uneven surface of the photosphere with its abnormal velocities. This is so far true that I derived my explanation, which I consider plausible, of the distribution of the spots in zones, from a consideration of the currents to which this very contact must give rise. I venture to return here for a moment to this explanation, and to complete it by a short explanatory table.

I consider that Professor Crew undoubtedly discovered the practically uniform angular velocity of all parts of the solar atmosphere. The lines whose displacement he measured are principally produced above the general level of photosphere, as Professor Young has seen nearly all of them reversed outside of the solar disk. But the lines which served Professor Dunér in his measurements of displacement having never been seen reversed outside the photosphere, I consider that they are produced (as are the greater part of the Fraunhofer lines) below the general level of the photosphere, in the openings between the photo-

* It appears to me that Mr. Maunder has done the same thing. In connection with a very interesting study which he has made of the movements of a group of spots, after having described the violence of the observed movements, he remarks "the argument, therefore, that the solar atmosphere must be quiescent because the external causes of storms and cyclones at work upon the Earth are absent there, is not valid" (Maunder: *Knowledge*, Sept., 1894, p. 200). This remark is perfectly just, but fortunately (as I have explained in the text) it is not directly applicable to my theory.

XUM

spheric clouds. Now as the gases in the openings must have taken up the velocity of these clouds, it is not at all surprising that Professor Dunér, when seeking to determine the velocity of the solar atmosphere, in reality measured the velocity of the photospheric clouds, which has long been known to vary with the latitude.

If this interpretation is correct, the Fraunhofer lines in the solar spectrum may be divided into three classes: 1st, *telluric lines*, which are unaffected by the solar rotation; 2nd, *lines of the solar atmosphere*, which are shown by Professor Crew's observations to be displaced by the solar rotation; 3rd, *photospheric solar lines*, which are shown by Professor Dunér's observations to be displaced by the solar rotation. This is a deduction from my theory which it ought not to be difficult to verify.

It is in any case clear that a new determination of the rotation of the solar atmosphere is very desirable; such a determination will not be conclusive unless preliminary study is devoted to the character of the lines to be employed in measuring the displacement.

If in the mean time my interpretation of the observations of Professors Crew and Dunér be regarded as correct, a very simple explanation of the distribution of the spots in zones may be derived from it.* This explanation comes out clearly from the following table:

I	II	III	IV	V	VI
Latitude b	Diurnal angle of rotation of the photosphere. (Duner)	Diurnal angle of rotation of the atmosphere. (Crew)	Difference II-III.	Heliocentric degrees subtended by a spot 1′ (geocentric) long. $\frac{23000}{108.5\times 60\times\cos b}$	No. of days in which a spot measuring 1′ (geocentric) will disappear. $\frac{V}{IV}$
0	14.14	13.72	+ 0.42	3.5	8.3
5	13 98	13.75	+ 0.23	3.53	15.3
11	13.80	13.80	0	3.57	∞
15	13.66	13.85	− 0.19	3.62	19.0
30	13.06	13.98	− 0.92	4.04	4 3
45	11.99	14.12	− 2.13	4.95	2 3
60	10.62	14.25	− 3.63	7.00	1.9

It is evident from the table that at a latitude of 11° the angular velocity of the photospheric clouds is exactly equal to that of the atmosphere above them. At higher latitudes the clouds move

* My theory (pp. 133-142) indicates that other causes may unite with those mentioned here to cause the distribution of the spots in zones.

more slowly than the atmosphere; at lower latitudes their velocity is greater. As this difference in velocity between the photospheric clouds and the overlying atmosphere must cause in the upper layers of the clouds either an acceleration or a retardation, it is only at the parallel of 11° that the lower layers are not veiled by the relative motion of the upper ones. In all other latitudes the veiling effect must show itself; its amount will be measured by the difference of the latitude from 11°.

Thus, if the spots are regarded as openings which are formed in all parts of the photosphere, they will be seen to have their greatest area near the parallel of 11°. At very different latitudes, whether higher or lower, their openings will rapidly disappear beneath the veils mentioned above.* At latitudes above 35°, the openings will be covered even before they have time to form. It appears from the table that while at 15° a spot measuring 1′ (geocentric) will not be covered in less than 19 days, at 30° such a spot will be covered in four days. At 45° the time required is only about 2 days. As so large a spot requires several days to form in the "royal zones, it does not seem at all surprising that in still higher latitudes no spots are visible; at best they are seen only as "veiled spots," or the "rudimentary spots" so frequently seen by Trouvelot, Secchi, Young and Lohse in all parts of the solar surface.†

DELFT, (HOLLAND) September 17, 1894.

ASTRO-PHYSICAL NOTES.

As announced elsewhere, ASTRONOMY AND ASTRO-PHYSICS has been purchased by the University of Chicago. Its publication will be continued as THE ASTROPHYSICAL JOURNAL, with the following Editorial staff:

EDITORS—George E. Hale, Director of the Yerkes Observatory; James E. Keeler, Director of the Allegheny Observatory.

* The long continued observations of Carrington and Spoerer show that spots are most numerous between the parallels of 10° and 15° (*Theorie du Soleil*, p. 134). This latitude must not be confused with the mean latitude of the spots at maximum; the latter is usually about 16°).

† Young: *Gen. Astron.*, p. 189. "Occasionally, what Trouvelot calls veiled spots are seen beyond the 45° limits, greyish patches surrounded by faculæ, which look as if a dark mass were submerged below the surface and dimly seen through a semi-transparent medium."—Secchi remarks that the entire solar surface is sometimes so covered with a dark network of black points "that one is inclined to see pores and rudiments of spots everywhere." (Secchi: *le Soleil*, I, p. 58.) That which Secchi says he is inclined to admit, and which Lockyer seems also to admit (*Chem. of the Sun*, p. 408,) is indicated by my theory to be a reality. In all latitudes openings are formed in the photosphere, and spots come into existence. But they cannot be distinguished as spots unless their dimensions are so great that their openings are not immediately closed by a photospheric veil, which comes between the lower depths of the opening and the observer.

XUM

ASSISTANT EDITORS—J. S. Ames, Johns Hopkins University; W. W. Campbell, Lick Observatory; Henry Crew, Northwestern University; E. B. Frost, Dartmouth College; F. L. O. Wadsworth, University of Chicago.

ASSOCIATE EDITORS—M. A. Cornu, École Polytechnique, Paris; N. C. Dunér, Astronomiska Observatorium, Upsala; William Huggins, Tulse Hill Observatory, London; P. Tacchini, Osservatorio del Collegio Romano, Rome; H. C. Vogel, Astrophysikalisches Observatorium, Potsdam, C. S. Hastings, Yale University; A. A. Michelson, University of Chicago; E. C. Pickering, Harvard College Observatory; H. A. Rowland, Johns Hopkins University; C. A. Young, Princeton University.

All correspondence relating to contributions and papers intended for publication should be addressed to George E. Hale, Kenwood Observatory, Chicago, U. S. A.

The Use of the Short-Focus Camera in Stellar Spectrum Photography.—There is still a word to be said about the short-focus camera in photographing celestial spectra. That it "applies effectively to the study of all large objects yielding bright-line spectra, comets, large nebulæ, aurora borealis, etc.," will hardly be called in question. I have said that very different principles are involved when it is used in photographing stellar spectra. Dr. Keeler contends [in the November ASTRONOMY AND ASTRO-PHYSICS] that it does not apply at all when the source of light is a star. I am unable to agree with him. My view of the question has been, and still is, that, other things being equal, we can reduce the exposure time for faint (and bright) stellar spectra in two entirely independent ways.

1. By using a prism train of lower dispersive power. Other things being equal, we decrease the length of photographed spectrum, and therefore the exposure-time, in proportion as we decrease the dispersive power of the prism train.

2. By reducing the focal length of the camera. Other things being equal, we reduce the length of the photographed spectrum, and therefore the exposure time, in proportion as we decrease the length of the camera. The *width* of the photographed spectrum need not be taken into account here, since it must be equally wide in all cases. I agree with Dr. Keeler that to *obtain* the necessary width, the "drift" of the star must be increased in proportion as we decrease the length of the camera; but it is the *drift on the slit* which must be increased, and not the drift *on the sensitive plate*. The drift on the plate is constant for all focal lengths. To obtain the increased drift on the slit does not call for increased clock *time*, but increased driving clock *rate*.

But let me put it in another way. In any given time the *quantity* of light entering the slit, and therefore the *quantity* of light falling upon the sensitive plate, are independent of the length of camera. We must assume that the width of photographed spectrum is constant and therefore independent of length of camera. The length of spectrum, and therefore the *area* of spectrum, vary with the length of the camera. Now if the quantity of light per unit of time is constant, and the area upon which it falls varies with the length of camera, the necessary exposure must also vary, and it will vary directly as the focal length of the camera. If we reduce the focal length one-half, we reduce the area of the photographed spectrum one-half; and since the quantity of light per unit of time is constant, we reduce the necessary exposure-time approximately one-half. To give the star the proper drift on the slit, the driving-clock rate must be increased four-fold.

Of course I have not advocated the use of the short camera when the object to be studied is bright; it reduces the scale of the photograph. But with faint ob-

jects, it is preferable to get *something* on the photograph with a short camera than to get *nothing* with a long camera. W. W. CAMPBELL.

Mt. Hamilton, 1894, Nov. 13.

Professor Campbell and I seemed to disagree only for the case when the source of light is a star, and from the above note we do not appear to really disagree even for that. I do not hold, and carefully avoided stating in my former note, that the short camera has *no* advantage over the long one (with the same apparatus) when the source is a star or body of very small angular magnitude, but I stated that the advantage is not the same in that case as it is for a body so large that no drift need be given to the image.

To illustrate my meaning, suppose that we have two cameras for the same instrument, one having the same focal length as the collimator and the other only half that length; and suppose that the photographed spectrum must have a breadth of one-fourth millimeter in order to be measurable.

Now let us suppose that we have to photograph the spectrum of a small body whose size is such that the diameter of the image on the slit-plate is one-half millimeter. In this case the short focus camera can be used; the photographed spectrum with stationary image will have a breadth of one-quarter millimeter, and the time of exposure (say ten minutes) will be only one-quarter of that required for the long focus camera.

To photograph the spectrum of another equally bright body whose image is only one fourth millimeter in diameter, we must either use the long camera or allow the image to drift its own diameter during the exposure. The latter course is equivalent to making two stationary exposures of ten minutes each, with the photographed spectra in juxtaposition. Hence with the same camera the exposure is twice as long as it was in the case of the larger, though equally bright object. As I said in my former note, "The same law (regarding length of exposure) does not hold as in the case of a large object, when drift becomes unnecessary." When the object is sufficiently large, the exposure is proportional to the square of the length of the collimator; when it is a star, the exposure is simply proportional to that length.

This is the same conclusion as that of Professor Campbell in the preceding note; but it seems to me that the difference between the two cases considered above is a very important one, and sufficient to justify what I previously said. By employing the short-focus camera when the object is large we reduce the length of exposure, partly by diminishing the breadth of the spectrum, which involves no sacrifice, and partly by diminishing its length, which is disadvantageous. But when the object is small, as a star, we shorten the time of exposure just in proportion as we sacrifice the length of the spectrum. Why not obtain the same length by using a lower dispersion with the long camera? I believe that, practically, the result would be better with the latter arrangement. The resolving power would be less, but the limit of resolution on a photograph always falls far short of its theoretical value. On the other hand, there would be less distortion and better definition throughout the range of the spectrum.

J. E. KEELER.

Platinum-on-Glass Mirrors.—*To the Editor of* ASTRO-PHYSICS. The extremely interesting article in the October number on the photography of the corona, in which work so much depends upon the perfection and stability of the reflecting surfaces employed, brings to our minds more forcibly than ever the extreme desirability of some process by which platinum surfaces can be produced upon glass.

Wrights' electrical process, by the deposit in a high vacuum of vapor from an induction spark, is admirable for small surfaces,—such as galvanometer mirrors; but is not applicable to large ones.

What is wanted is a chemical method, similar to that of silvering, by which a coherent film is deposited from a solution. I venture, in view of the importance of the matter, to refer to some incomplete experiments of my own which seem capable of solving the problem.

I send you a small mirror, about 3 × 2 c. m., which was coated by such a chemical process. I have rubbed this mirror *hard* with the fingers, with rouge, washed it in hot and cold water, and with strong nitric acid. It seems as permanent as the glass upon which it is deposited.

The method is as follows:

SOLUTION I.

Chloroplatinite of potassium 1 gram. Water 6 c. c.

SOLUTION II.

Make a 5 per cent solution of neutral potassium oxalate. Warm 100 c. c. of this and add ferric oxalate 20 grams. Filter and keep in the dark or in a black bottle.

Clean the glass as for silvering. Mix equal parts of I and II. Have the glass dry and warm; pour a thin layer of the mixed solutions upon it, and place it in strong sunlight.

The surface tension of the liquid prevents it from running over the edge of the glass, and the plate may be rocked about, if the liquid layer be not too thick.

Light reduces the ferric oxalate, which dissolves in potassium oxalate and reduces the platinum.

I have experimented upon ordinary lantern slide glasses (3¼ × 4-in.), and have sometimes secured perfect films over the entire surface. Unfortunately however, there is no certainty about the action, and failure has been more frequent than success. When you get a good film it is very good indeed, and I write this hoping that someone may be able to suggest some modification by which the action may be made certain.

Of course I have tried great numbers of modifications, but thus far have produced nothing better than the above. The fact that it will sometimes work to perfection is proof nevertheless that it can be made to always do so.

Bowdoin College, Brunswick, Me., Oct. 22. C. C. HUTCHINS.

The small platinum mirror sent us by Professor Hutchins is of such excellence as to demonstrate the value of the chemical method of depositing films of platinum upon glass. On account of its permanence, a platinum-on-glass mirror would possess a considerable advantage over the ordinary silver-on-glass mirror, which must frequently be renewed. It is to be hoped that further experiments will be made for the purpose of perfecting the interesting chemical process here described.

Experiments on the Radiation of Heated Gases.—In the October number of *Knowledge*, Mr. Evershed describes some experiments on a subject to which renewed interest has recently been given by the researches of Pringsheim and Smithells,—the origin of bright-line spectra. The experiments were made for the purpose of ascertaining whether the heated vapor of iodine obeys Kirchhoff's law, and whether metallic vapors can be made to emit their characteristic radiations by heat alone, chemical and electrical action being excluded.

In Mr. Evershed's apparatus, which was simply though ingeniously con-

trived, iodine was vaporized in a glass tube filled with a neutral gas, by means of a Bunsen burner. The tube was filled with a bright glow, the spectrum of which was continuous and not resolvable by a powerful spectroscope, although the absorption spectrum of the vapor at the same time, obtained by sending a beam of white light through the tube, was the ordinary banded spectrum, unaccompanied by signs of continuous absorption. Hence the absorbed and emitted rays differed in quality, and iodine vapor at this temperature does not obey Kirchhoff's law.

When metallic sodium was tried instead of iodine, the tube was at first filled with a bright glow, which gave a continuous spectrum (with a dark band at D due to the cooler vapor near the end of the tube) and which was nearly opaque to transmitted white light. As the density of the vapor diminished, the continuous spectrum contracted into a rather wide bright line at D, having a dark line in its center. The corresponding changes in the absorption spectrum were as follows: at first the only light transmitted was a bright band in the violet; a green band was then added and finally a red one. These bands gradually widened until only the dark space between the last two remained, which narrowed and became the dark D line. To the unaided eye the vapor was then perfectly transparent.

In these phenomena Mr. Evershed sees the connecting link between the radiation of the colored vapors of the metalloids and the line spectra of the metals, and his inference is that a sufficiently high temperature, coupled with not too great a density, is alone sufficient to make any gas emit its charateristic radiation. We are not compelled to assume the operation of chemical or electrica forces. The light from the calcium and hydrogen of the chromosphere is proba bly directly due to the great temperature to which these gases are raised under the solar conditions.

The Spectrum of Mars.—Since writing the note on the spectrum of Mars printed in your last number, I find that Professor Campbell does mention incidentally that the early observer sought to eliminate the effect of our atmosphere by observations of the Moon; but the sentence I quoted seemed to me to suggest the interpretation I put upon it, and to need the explanation I gave of my early work.

WILLIAM HUGGINS.

On Selecting Suitable Nights for Observing Planetary Spectra.—In the November, ASTRONOMY AND ASTRO-PHYSICS, p. 771, Dr. Huggins has quoted a part of a paragraph from my paper on *The Spectrum of Mars:*

"It is very important, as Janssen pointed out in 1867, that we eliminate as far as possible the effect of aqueous vapor in our own atmosphere. The observers do not seem to have taken this factor into account (except Janssen, the details of whose observations appear to be unpublished)."

So far as the above statement, taken by itself, is concerned, I agree with Dr. Huggins that it is very "far from being correct." But the passage quoted is incomplete, and its apparent meaning bears very little relation to what I really said. Dr. Huggins overlooked and omitted the important first half of the sentence, but quoted the subordinate second half, and naturally therefore missed the point. If we place the omitted half-sentence at the beginning of the quoted passage, the meaning will become clear. In enumerating the advantages of Mt. Hamilton for making such observations, I mentioned: "(4) The very dry summer air prevailing here. The average relative humidity is very low at Mt.

Hamilton for the months of July and August. In many years it is less than 35 per cent. There is no difficulty in selecting nights for observing the spectrum of Mars when our relative humidity is not more than 20. This is a very important factor, since in examining Mars' spectrum for evidences of aqueous vapor it is very important, as Janssen pointed out in 1867, that we eliminate as far as possible the effect of aqueous vapor in our own atmosphere. The observers do not seem to have taken this factor into account (except Janssen* the details of whose observations appear to be unpublished). By examining the contemporary weather data, I find that some of the observations were made when the relative humidity was 81, 85 and even 90. All the principal published observations were made where the average relative humidity at those seasons of the year is something like 80."

It will be seen that the subject of that paragraph is *relative humidity*. It will also be seen that the half-sentence overlooked by Dr. Huggins, "This is a very important factor, etc.," refers to the factor *relative humidity*. It must also be evident that the expression quoted by him, "The observers do not seem to have taken this factor into account," refers to the factor *relative humidity*, and not to aqueous vapor in general. I do not understand that Dr. Huggins did take the factor relative humidity into account. Its importance does not seem to be generally understood, and I shall briefly state its bearing upon the problem.

In order to eliminate the effects of our own atmosphere and whatever it may contain, it is sufficient, theoretically, to observe the spectra of Mars and the Moon when these bodies have equal altitudes; and Dr. Huggins will find in the paragraph next following the one from which he quoted that I gave the observers full credit for employing that method when I wrote "the observers sought to eliminate the effect of our atmosphere and its aqueous vapor by observing the lunar spectrum when the Moon was at the same altitudes."

Now while that method is theoretically sufficient, practically, it is not. It would be theoretically sufficient to observe the Moon and Mars *as soon as they appear above the horizon;* but practically, every observer would wait, or ought to wait, until they are near their maximum altitude, in order to eliminate as far as possible from both spectra the effects of our own atmosphere. If, for example, the altitudes of these bodies at one time are only 25° and at another time are 60°, the relative thicknesses of atmosphere passed through by the rays of light are about as 2 to 1, and clearly there would be a great advantage in observing at the altitude 60°. Similarly, if the relative humidity of our atmosphere at one time is 90 per cent and at another time is only 45, clearly the latter time should be preferred for observation.† If it is important to reduce the thickness of the stratum of the atmosphere by observing when Mars and the Moon have great altitudes rather than low ones, it is equally important to observe when the relative humidity of the atmosphere is low rather than when it is high. Janssen deserves great credit for ascending Mt. Etna to make observations of Mars' spectrum. By so doing he eliminated nearly half our atmosphere and probably much more than half the aqueous vapor. If that was worth doing, we on the surface ought to eliminate the aqueous vapor *as far as possible* by selecting nights for the observations when the relative humidity is low.

W. W. CAMPBELL.

Mt. Hamilton, Nov. 19, 1894.

* To avoid misunderstanding, I explain that this is meant in the sense of "except possibly Janssen," since we have not the details of his observations and they appear to be unpublished.

† Of course the relative humidity at the surface of the Earth is probably not the same as the relative humidity at higher levels, but the former must be our guide.

PLANET NOTES FOR JANUARY.

H. C. WILSON.

Mercury will be at superior conjunction, that is, on the farther side of the Sun, Jan. 9 and so will not be visible during this month.

Venus will be evening planet, setting too soon after the Sun to be in good position for observation. Venus will be in conjunction with the one-day-old Moon, 1° 21′ north of the latter, at 9 o'clock on the evening of Jan. 26.

Earth will be at perihelion Jan. 2 at 6^h P. M.

Mars will be in conjunction with the Moon, about 2° south of the latter, at 2^h P. M. Jan. 5. By this time all our readers will have become so familiar with the aspect of the ruddy planet in Pisces that we have no need to point out its location. During January it will be west of the meridian in the evening and will set shortly after midnight. Up to Nov. 23 the south polar snow-cap had not reappeared.

Jupiter is in Gemini and his brilliancy on some of these clear sparkling nights is sufficient to cast respectable shadows of large objects upon the white background of the snow. He is in his best position for observation during this opposition. The belts show plainly in a very small telescope and the details shown on the planet's surface by a large telescope on a good night will defy the power of an artist to depict them. The four bright satellites may always be seen, except when they are behind or in the shadow of the planet and when in transit across the disc. Under some circumstances they may also be seen in transit and their shadows, cast as black round dots upon the planet, are quite conspicuous when the seeing is good. We warn the reader, however, not to attempt to see the new (fifth) satellite, discovered by Barnard, for it can only be seen with the aid of a very powerful telescope. The smallest telescope with which it has been seen, so far as we are aware, is the 18-inch of Dearborn Observatory, Evanston, Ill.

Saturn and *Uranus* are hardly yet in good position for the amateur. They may be observed in the morning. Saturn will be at quadrature, 90° west from the Sun, Jan. 26. He will be in conjunction with the Moon, about 6° north of the latter, Jan. 18 at 1 P. M. Uranus will be in conjunction with the Moon, about 5° north of it, on the 19th at 11^h 35^m A. M. Saturn is in Virgo near the west boundary of Libra, moving slowly eastward. Uranus is in Libra a little southeast of the star ν.

Neptune is in Taurus a little south and west from the star ι and moving slowly westward.

Planet Tables for January.

[The times given are local time for Northfield. To obtain Standard Times for Places in approximately the same latitude, add the difference between Standard and Local Time if west of the Standard Meridian or subtract if east].

MERCURY.

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
	h m	° ′	h m	h m	h m
Jan. 5	19 2.1	− 24 27	7 37.1 A. M.	11 55.0 A. M.	4 12.6 P. M.
15	20 6.3	− 22 24	7 58.0 "	12 26.8 "	4 54.8 "
25	21 16.8	− 19 39	8 7.0 "	12 57.7 "	5 47.4 "

VENUS.

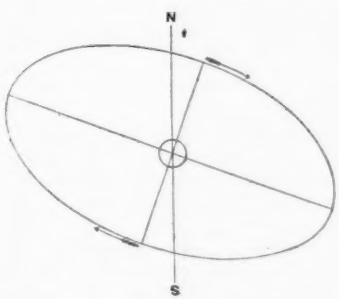
Jan. 5	19 43.9	− 22 26	8 15.6 A. M.	12 43.6 P. M.	5 11.6 P. M.
15	20 36.9	− 19 58	8 16.8 "	12 57.4 "	5 30.4 "
25	21 27.6	− 16 32	8 12.7 "	1 8.7 "	5 57.5 "

Date. 1894.	R. A. h m	Decl. °	Rises. h m	Transits. h m	Sets. h m.
			MARS.		
Jan. 5.....	1 59.0	+13 20	12 0.0 M.	6 57.3 P. M.	1 54.6 A. M.
15.....	2 15.8	+14 56	11 30.5 A. M.	6 34.7 "	1 38.9 "
25.....	2 34.5	+16 34	11 01.7 "	6 12.9 "	1 24.1 "
			JUPITER.		
Jan. 5.....	5 57.4	+23 16	3 11.5 P. M.	10 55.3 P. M.	6 39.1 A. M.
15.....	5 52.3	+23 16	2 27.1 "	10 10.9 "	5 54.7 "
25.....	5 48.2	+23 17	1 43.8 "	9 27.6 "	5 11.4 "
			SATURN.		
Jan. 5.....14	17.4	−11 14	1 56.5 A. M.	7 15.0 A. M.	12 33.5 P. M.
15.....14	19.8	−11 23	1 19.8 "	6 37.9 "	11 56.0 "
25.....14	21.5	−11 29	12 42.9 "	6 0.3 "	11 18.7 "
			URANUS.		
Jan. 5.....15	6.1	−17 7	3 9.8 A. M.	8 3.2 A. M.	12 56.6 P. M.
15.....15	7.7	−17 12	2 32.8 "	7 25.8 "	12 18.8 "
25.....15	8.7	−17 18	1 54.0 "	6 47.3 "	11 39.8 A. M.
			NEPTUNE.		
Jan. 5.....	4 34.9	+20 56	2 15.9 P. M.	9 47.7 P. M.	5 11.9 A. M.
15.....	4 40.7	+20 55	1 35.6 "	9 7.4 "	4 39.2 "
25.....	4 57.0	+20 54	12 55.6 "	8 27.4 "	3 59.2 "
			THE SUN.		
Jan. 5.....19	6.0	−22 35	7 36.7 A. M.	12 5.7 P. M.	4 34.7 P. M.
15.....19	49.5	−21 04	7 34.3 "	12 9.7 "	4 45.1 "
25.....20	31.6	−18 53	7 28.2 "	12 12.6 "	4 56.9 "

Occultations Visible at Washington.

Date 1895	Star's Name.	Magnitude.	IMMERSION Washington M. T.	IMMERSION Angle f'm N p't.	EMERSION Washington M. T.	EMERSION Angle f't N p't.	Duration.
			h m	°	h m	°	h m
Jan. 1	φ Aquarii	4.1	8 13	61	9 20	229	1 07
1	96 Aquarii	5.6	11 29	31	12 13	276	0 44
4	100 Piscium	6.8	13 38	27	14 17	293	0 39
11	γ Cancri	4.3	13 31	177	14 09	337	0 38
14	80 Cancri	6.8	9 01	128	9 54	284	0 53
18	B.A.C. 4923	7.3	14 37	93	15 31	326	0 54
19	B.A.C. 5197	6.0	12 54	66	13 31	339	0 37
27	42 Aquarii	5.8	7 04	9	7 43	288	0 39

The Satellite of Neptune.



APPARENT ORBIT OF THE SATELLITE OF NEPTUNE, AS SEEN IN AN INVERTING TELESCOPE.

CENTRAL TIMES OF GREATEST ELONGATIONS.

Period $5^d\ 21^h.045$.

Northeast.	Northwest.
Dec. 29 5.9 P. M.	Jan. 1 4.5 P. M.
Jan. 4 3.0 "	7 1.6 "
10 12.2 "	13 10.7 A. M.
16 9.2 A. M.	19 7.8 "
22 6.3 "	25 4.9 "
28 3.4 "	31 2.0 "

In the diagram the central circle represents the planet and is drawn to the same scale as the orbit of the satellite.

Phenomena of Jupiter's Satellites.

Central Time.

		h	m				h	m		
Jan.	1	11	38 P. M.	I	*Oc. Dis.	Jan. 11	7	23 P. M.	I	*Tr. Eg.
	2	2	9 A. M.	I	*Ec. Re.		7	54 "	I	*Sh. Eg.
		2	4 P. M.	II	Tr. In.	12	2	15 "	I	Oc. Dis.
		2	36 "	II	Sh. In.		5	1 "	I	*Ec. Re.
		4	41 "	II	Tr. Eg.	13	5	28 A. M.	II	Tr. In.
		5	14 "	II	*Sh. Eg.		6	31 "	II	Sh. In.
		8	57 "	I	*Tr. In.		8	4 "	II	Tr. Eg.
		9	14 "	I	*Sh. In.		9	10 "	II	Sh. Eg.
		11	13 "	I	*Tr. Eg.		11	33 "	I	Tr. In.
		11	30 "	I	*Sh. Eg.		12	6 P. M.	I	Sh. In.
	3	6	5 "	I	*Oc. Dis.		1	49 "	I	Tr. Eg.
		7	56 "	III	*Tr. In.		2	22 "	I	Sh. Eg.
		8	37 "	I	*Ec. Re.	14	8	42 A. M.	I	Oc. Dis.
		9	10 "	III	*Sh. In.		11	30 "	I	Ec. Re.
		10	45 "	III	*Tr. Eg.		12	42 P. M.	III	Oc. Dis.
	4	12	2 A. M.	III	*Sh. Eg.		5	47 "	III	*Ec. Re.
		9	0 "	II	Oc. Dis.	15	12	22 A. M.	II	*Oc. Dis.
		12	13 P. M.	II	Ec. Re.		4	6 "	II	Ec. Re.
		3	23 "	I	Tr. In.		6	0 "	I	Tr. In.
		3	43 "	I	Sh. In.		6	34 "	I	Sh. In.
		5	39 "	I	*Tr. Eg.		8	16 "	I	Tr. Eg.
		5	59 "	I	*Sh. Eg.		8	51 "	I	Sh. Eg.
	5	12	31 "	I	Oc. Dis.	16	3	8 "	I	*Oc. Dis.
		3	6 "	I	Ec. Re.		5	58 "	I	Ec. Re.
	6	3	12 A. M.	II	*Tr. In.		6	37 P. M.	II	*Tr. In.
		3	54 "	II	*Sh. In.		7	50 "	II	*Sh. In.
		5	48 "	II	Tr. Eg.		9	14 "	II	*Tr. Eg.
		6	32 "	II	Sh. Eg.		10	29 "	II	*Sh. Eg.
		9	49 "	I	Tr. In.	17	12	26 A. M.	I	*Tr. In.
		10	11 "	I	Sh. In.		1	3 "	I	*Sh. In.
		12	5 P. M.	I	Tr. Eg.		2	42 "	I	*Tr. Eg.
		12	28 P. M.	I	Sh. Eg.		3	20 "	I	*Sh. Eg.
	7	6	57 A. M.	I	Oc. Dis.		7	35 "	IV	Ec. Dis.
		9	23 "	III	Oc. Dis.		8	7 "	IV	Ec. Re.
		9	34 "	I	Ec. Re.		9	35 P. M.	I	*Oc. Dis.
		1	46 P. M.	III	Ec. Re.	18	12	27 A. M.	I	*Ec. Re.
		10	7 "	II	*Oc. Dis.		2	34 "	III	*Tr. In.
	8	1	30 A. M.	II	*Ec. Re.		5	9 "	III	Sh. In.
		4	15 "	I	*Tr. In.		5	24 "	III	Tr. Eg.
		4	40 "	I	*Sh. In.		8	4 "	III	Sh. Eg.
		6	31 "	I	Tr. Eg.		1	30 P. M.	II	Oc. Dis.
		6	56 "	I	Sh. Eg.		5	23 "	II	*Ec. Re.
	9	12	3 "	I	*Oc. Dis.		6	52 "	I	*Tr. In.
		4	3 "	I	*Ec. Re.		7	32 "	I	*Sh. In.
		4	20 "	II	Tr. In.		9	9 "	I	*Tr. Eg.
		5	13 P. M.	II	*Sh. In.		9	48 "	I	*Sh. Eg.
		6	56 "	II	*Tr. Eg.	19	4	1 "	I	Oc. Dis.
		7	51 "	II	*Sh. Eg.		6	56 "	I	*Ec. Re.
		10	41 "	I	*Tr. In.	20	7	47 A. M.	II	Tr. In.
		11	8 "	I	*Sh. In.		9	9 "	II	Sh. In.
	10	12	57 A. M.	I	*Tr. Eg.		10	24 "	II	Tr. Eg.
		1	25 "	I	*Sh. Eg.		11	48 "	II	Sh. Eg.
		7	49 P. M.	I	*Oc. Dis.		1	19 P. M.	I	Tr. In.
		10	32 "	I	*Ec. Re.		2	1 "	I	Sh. In.
		11	14 "	III	*Tr. In.		3	35 "	I	Tr. Eg.
	11	1	9 A. M.	III	*Sh. In.		4	17 "	I	Sh. Eg.
		2	3 "	III	*Tr. Eg.	21	10	28 A. M.	I	Oc. Dis.
		4	3 "	III	*Sh. Eg.		1	25 P. M.	I	Ec. Re.
		11	14 "	II	Oc. Dis.		4	5 "	III	Oc. Dis.
		2	48 P. M.	II	Ec. Re.		6	54 "	III	*Oc. Re.
		5	7 "	I	*Tr. In.		7	2 "	III	*Ec. Dis.
		5	37 "	I	*Sh. In.		9	48 "	III	*Ec. Re.

	h	m						h	m			
Jan.	22	2	39	A. M.	II	*Oc. Dis.	Jan.	27	10	8	A. M.	II Tr. In.
		6	41	"	II	Ec. Re.			11	46	"	II Sh. In.
		7	45	"	I	Tr. In.			12	45	P. M.	II Tr. Eg.
		8	29	"	I	Sh. In.			2	26	"	II Sh. Eg.
		10	1	"	I	Tr. Eg.			3	3	"	I Tr. In.
		10	46	"	I	Sh. Eg.			3	55	"	I Sh. In.
	23	4	54	"	I	Oc. Dis.			5	21	"	I *Tr. Eg.
		7	54	"	I	Ec. Re.			6	12	"	I *Sh. Eg.
		8	57	P. M.	II	*Tr. In.		28	12	15	"	I Oc. Dis.
		10	28	"	II	*Sh. In.			3	20	"	I Ec. Re.
		11	34	"	II	*Tr. Eg.			7	32	"	III *Oc. Dis.
	24	1	7	A. M.	II	*Sh. Eg.			10	22	"	III *Oc. Re.
		2	11	"	I	*Tr. In.			11	3	"	III *Ec. Dis.
		2	58	"	I	*Sh. In.		29	1	50	A. M.	III *Ec. Re.
		4	28	"	I	Tr. Eg.			4	58	"	II Oc. Dis.
		5	15	"	I	Sh. Eg.			9	16	"	II Ec. Re.
		11	21	"	I	*Oc. Dis.			9	52	"	I Tr. In.
	25	2	23	"	I	*Ec. Re.			10	24	"	I Sh. In.
		5	58	"	III	Tr. In.			11	48	"	I Tr. Eg.
		8	47	"	III	Tr. Eg.			12	41	P. M.	I Sh. Eg.
		9	9	"	III	Sh. In.		30	6	41	A. M.	I Oc. Dis.
		12	4	P. M.	III	Sh. Eg.			9	49	"	I Ec. Re.
		3	48	"	II	Oc. Dis.			11	19	P. M.	II *Tr. In.
		4	39	"	IV	Sh. In.		31	1	5	A. M.	II *Sh. In.
		5	46	"	IV	*Sh. Eg.			1	56	"	II *Tr. Eg.
		7	58	"	II	*Ec. Re.			3	45	"	II Sh. Eg.
		8	38	"	I	*Tr. In.			3	59	"	I Tr. In.
		9	26	"	I	*Sh. In.			4	53	"	I Sh. In.
		10	52	"	I	*Tr. Eg.			6	15	"	I Tr. Eg.
		11	43	"	I	*Sh. Eg.			7	9	"	I Sh. Eg.
	26	5	48	"	I	*Oc. Dis.	Feb.	1	1	8	A. M.	I *Oc. Dis.
		8	51	"	I	*Ec. Re.			4	18	"	I Ec. Re.
									9	26	"	III Tr. In.

NOTE.—In., denotes ingress; Eg., egress; Dis., disappearance; Re., reappearance; Ec., eclipse. Oc., denotes occultation; Tr., transit of the satellite; Sh. transit of the shadow; * Visible at Washington.

Phases and Aspects of the Moon.

	Central Time.				
	d		h	m	
First Quarter	Jan.	4	1	52	A. M.
Full Moon		11	12	50	A. M.
Perigee		11	6	10	P. M.
Last Quarter		17	4	55	P. M.
New Moon		25	3	26	P. M.
Apogee		26	11	10	A. M.

Transit of Mercury, Nov. 10, 1894.—Instructions for observing this transit of Mercury were issued to observers in the United States generally, by the Naval Observatory, at Washington, D. C. Additional suggestions were sent out by Professor S. Newcomb, Supt. of the American Ephemeris and Nautical Almanac. The following reports have been received :—

Lowell Observatory, Flagstaff, Arizona.—Mercury began by being behind time. To Professor Pickering, who awaited at the six-inch his entrance on the solar disk, he failed to appear till a minute (by transmitted W. U. T.) after he was expected.

Ingress, exterior contact occurring at $3^h\ 57^m$ G. M. T.
instead of $3^h\ 56^m\ 2^s$ G. M. T.
and Ingress, interior contact occurring at $3^h\ 58^m\ 40^s$ G. M. T.
instead of $3^h\ 57^m\ 46^s$ G. M. T.

The usual phenomena were all more or less visible and all more or less palpably due to any cause but Mercury. In detail they were as follows:

After having delayed, partly from irradiation, partly from the present imperfection of his theory, from appearing on time, he further clung to the sky. Professor Pickering observed, in the manner noted by Huggins in 1868, the planet assuming when a little more than half way on the shape of a beehive, irradiation destroying the solar cusps entirely. Professor Pickering saw no aureole just before interior contact, such as has been observed in the case of Venus.

When fully on he appeared to me perfectly round and decidedly darker than the sun-spots, in about the proportionate intensities of Forster's estimate of 1848, that is 8 to 5. With an ordinary eye-piece, power 180, and two pieces of glass one red, the other green, used together, both Professor Pickering and I saw a bright halo surrounding the planet which we each attributed unhesitatingly to contrast. With a solar eye-piece and an ordinary eye-piece, power 200, capped with the usual dark glass cap, the halo was not visible, but Professor Pickering observed it again when the two pieces of dark glass were substituted for the usual cap. These were much darker than the cap as the Sun could be well scanned by the naked eye through them while the glare was too great through the cap.

On the planet's disk I imagined a tiny bright speck, *s. f.* which very obligingly turns out to agree with Jenkins' formulæ. But I think I remember several other specks—Professor Pickering also saw similiar imperfections, which we neither of us were in the least inclined to impute to Mercury. Professor Pickering made every attempt to see the so-called diffraction spot first by looking for it in the usual way and then by maltreating the instrument in every conceivable manner, by diaphraming it down to 2.3 inches aperture, then to 1 inch, and finally unscrewing the lens unequally on the sides, but was quite unsuccessful in making it accomplice to any evil result.

Throughout I noticed that the planet's disk was fringed internally by a penumbra of ray-like character resembling the penumbræ of sunspots, which extended in equally on all sides to about two-fifths of the radius. It was visible under all instrumental and atmospheric conditions. Professor Pickering also saw this but to him it seemed like a light, hazy band extending in to the same distance. He attributes it to superposed images of the planet's disk; to me it appears probably to be an interference effect.

Photographs of the planet in transit were taken at my suggestion by Mr. Douglass. They are of the usual excellence of photographs of the planets and enable anyone of sufficient faith to make out an impression on the plate of Mercurial appearance, when it has once been pointed out to him.

Mercury at Egress.

At egress I noted a curious series of irradiation effects. The beehive aspect was assumed in due course, and when about two-thirds off the disk of the sun, the planet put out a couple of appendages, one on either side, like small wings, peculiarly appropriate to Mercury shown in the accompanying sketch. Thus prepared, the planet took flight into space at $9^h\ 13^m\ 5^s$ G. M. T., or like his entrance from it, late. PERCIVAL LOWELL.

Lowell Observatory, Nov. 12, '94.

Davidson Observatory, San Francisco, California.—I herewith inclose you the results of observations on the the transit of Mercury, Nov. 10, 1894,

by Messrs. Fremont Morse of the United States Coast and Geodetic Survey and Chas. B. Hill formerly of the Survey and later of the Lick Observatory.

My own results were unsatisfactory and I will not publish them. We were fully prepared for the early observations ($7^h\ 46^m$ A. M.) and had a free horizon, but unfortunately we were on the wrong side of the dense fog.

The best seeing we had was when the fog was thinning and before the atmosphere became very unsteady.

During the progress of the transit I looked many times at the planet through both the Fraunhofer telescopes, and on one occasion in the telescope Mr. Hill was using I saw a very faint whitish aureola around the planet, fully a diameter of the planet in breadth and not brightest in contact with the planet; and also a very faint, whitish, nebulous centre on the planet.* It was the first time I had seen such a phenomenon in transits of Mercury or Venus; and I changed my position several times to be sure of the exhibition. I attributed it to the atmospheric conditions: the air was very unsteady at times, and there was little or no wind.

I observed the meridian passages of the Sun and planet in the transit instrument.

GEORGE DAVIDSON.

Observations of Chas. B. Hill.—I used the "Fraunhofer" telescope, on tripod stand, aperture 3 inches, power about 120 diameters, and with a deep red shade glass. Sidereal chronometer No. 1739 used in these observations was 5.1 secs. slow of local sidereal time, as determined by comparisons before and after contact with the standard chronometer of the U. S. Coast and Geodetic Survey Observatory.

In the morning a dense fog prevented all possible chance of obtaining contacts I and II. At egress the sky was clear, but the atmosphere was very unsteady, and the contacts were observed as well as the conditions would permit, but not very satisfactorily. The instants as noted by the chronometer were:

III.	16^h	21^m	20^s	"not yet"
	16	21	40	"not yet"
	16	21	51?	contact
	16	22	03	past.
IV.	16	23	22	doubtful
	16	23	31	gone

Assuming that the instant marked "contact?", and the mean of the two last times recorded, represent respectively the best values of III and IV to be obtained from these observations, and reducing to Pacific Standard Time, we have

III. $1^h\ 11^m\ 36^s.8$
IV. 1 13 12. 1 P. M.

Davidson Observatory, Nov. 17th 1894. CHAS. B. HILL.

Fremont Morse Observations.—Fog prevented the observation of the I and II contacts, and I did not go to the Observatory until about an hour and a half before the end of the transit.

The instrument used was one of the large reconnoitering telescopes of the Coast and Geodetic Survey, having an aperture of 3 inches, and a power of 105. A dark yellow glass gave a very satisfactory shade, the image of the sun being neither too bright nor too dark.

The atmosphere was unsteady, but with the low power used the disturbance was not so great as to cause much trouble.

---

* I think Dr. Huggins has recorded a similar phenomenon.

The recorded and reduced times are as follows:

Contact.	Time by Chro. 5038 M. T.			Chro. fast of Pacific Standard Time.			Pacific Standard Time of Contacts.		
	h	m	s	h	m	s	h	m	s
III	1	20	15.5	0	08	42.6	1	11	32.9
IV	1	22	01.0				1	13	18.4

FREMONT MORSE,
Assistant Coast and Geodetic Survey.

Davidson Observatory, Nov. 19, 1894.

Halsted Observatory, Princeton, N. J.—The weather permited us to do nothing except to observe the two contacts at *ingress*. At egress the Sun was hidden, and during the time the planet was on the Sun it was so generally overcast that no micrometrical or spectroscopic observations were even attempted.

At the Halsted Observatory with the 23-inch telescope the observations were made by myself—external contact at $10^h\ 56^m\ 39^s$, and internal (breaking of black ligament) at $10^h\ 58^m\ 22^s$. At the School of Science Observatory with the 9½-inch telescope Professor Reed noted the external contact as already obvious at $10^h\ 56^m\ 46^s$; and the internal at $10^h\ 58^m\ 25^s$. We both observed through thin clouds.

C. A. YOUNG.

Agricultural College, Brookings, S. D.—President Lewis McLouth observed the transit using a five-inch glass, power 240. A full report was given with drawings showing several positions of the planet near egress. No black drop was seen, the planet and limb of the Sun were very clear and distinct. The times of contacts were:

	Central Standard Time.		
Second interior contact	3^h	11^m	18^s
Bisection of planet	3	12	23
Second exterior contact	3	13	02

Chabot Observatory, Oakland, California.—The third and fourth contacts of the transit, were observed with 8½-inch equatorial, power 200. The other two were lost by fog. The seeing was 3 on a scale of 5 at 3d contact, but very poor at 4th, making it uncertain by 3 or 5 seconds:

	Standard Pacific Time.		
Third contact	1^h	11^m	$39^s.0$
Fourth contact	1	13	18.5

Charles Burckhalter was observer.

Leander McCormick Observatory, University of Virginia.—Professor O. Stone reports observations with 4-inch Kahler equatorial, power 110 diameters. Edgar Odell was observer, eye and ear, with chronometer.

	Eastern Standard Time.			
	h	m	s	
I	10	56	59.5	
		58	31.0	Mercury's disk still not circular.
			33.5	Ligament one-fourth diameter of Mercury.
			37.5	Drop nearly square.
II	10	58	45.0	Minimum drop
			47.0	Circle of light complete.
III	4	11	12.5	Geometrical contact.
IV	4	12	55.5	

Definition for I and II good; not a cloud in the sky. Definition for III and IV poor; Sun came out through a rift in heavy clouds just long enough to observe the contacts.

The Transit of Mercury.—At Northfield the sky was densely cloudy on the morning of Nov. 10, and there were some flurries of snow. Shortly before the beginning of the transit, however, the clouds began to break away and we were able to get the instruments into adjustment on the east limb of the Sun. Professor Payne observed with the 16-inch refractor and polarizing helioscope, power 290, and Miss C. R. Willard with the 5-inch finder by projection of an inch image. Dr. Wilson observed with the 5-inch companion to the photographic telescope, focal length 9 feet, with a diagonal eyepiece power 200, and neutral tint glass shade.

At first contact a cloud covered the Sun. It passed partly off and Miss Willard first caught sight of the planet a little more than half on the disc at 9^h 58^m 21^s A. M., Central Standard time. She saw the light completely surround the planet at 9^h 58^m $50^s.5$.

Professor Payne saw the planet first at 9^h 58^m 23^s, estimated geometrical internal contact at 9^h 58^m $32^s.5$ and the meeting of the cusps of light at 9^h 58^m $44^s.0$. The limb was very unsteady and he did not feel certain of the times within several seconds.

Dr. Wilson did not see the planet until after the contact was complete, as the glass shade was too dense to show the Sun through the clouds, and it could not readily be changed. A number of photographs were taken soon after contact and at intervals during the transit, but the seeing was so poor that they are of little value.

At egress the sky was at first clear, but the seeing very unsteady, and a thin cloud passed over just before the planet disappeared. Professor Payne noted the separation of the cusps of light at 3^h 11^m $29^s.5$ P. M., geometrical internal contact at 3^h 11^m $31^s.0$, half off at 3^h 12^m $28^s.6$ and disappearance at 3^h 13^m $01^s.8$.

Dr. Wilson noted the separation of the cusps at 3^h 11^m $28^s.4$, geometrical contact at 3^h 11^m $34^s.5$, half off at 3^h 12^m $15^s.5$ and disappearance at 3^h 13^m $11^s.4$. The image in this telescope was quite sharp most of the time but was very unsteady.

Miss Willard noted the separation of the cusps at 3^h 11^m $19^s.2$, geometrical contact at 3^h 11^m $27^s.2$, half off at 3^h 12^m $01^s.6$ and disappearance at 3^h 12^m $50^s.0$.

Professor Payne and Dr. Wilson recorded time by chronograph, Miss Willard by calling time to an assistant, who read the time from a sidereal chronometer.

COMET NOTES.

Rediscovery of Encke's Comet.—Encke's periodic comet was discovered on its return by Cerulli at Teramo on Nov. 1. Its position Nov. 4, Berlin noon, was: R. A. 23^h 8^m 8^s; Decl. $+$ 13° 36′. Its daily motion was $-$ 2^m 16^s in R. A. and $-$ 16′ in declination. Owing to bad weather we have not yet looked it up at Northfield.

Ephemeris of Encke's Comet.—In *Astronomische Nachrichten*, No. 3263, Dr. Backlund gives the following elements of Encke's comet for 1895:

Epoch and Osculation 1894 Dec. 11.0 Berlin mean time.

$M = 343° 21′ 31″.84$
$\pi = 158\ 42\ 18\ .92$
$\Omega = 334\ 44\ 51\ .27$
$i = 12\ 54\ 24\ .47$

$\varphi = 57° 48′ 14″.01$
$\mu = 1074″.10793$
$\mu' = +\ 0″.069299$

Perihelion passage will take place Feb. 4, 1895. In 1862 it fell upon Feb. 6. In 1891 the comet was at its shortest distance from Mercury so that the perturbations by this planet were considerable. Two or three more revolutions of the comet, together with the apparitions of 1819—1858 and 1871—1891, will afford a good check upon the determinations of the mass of Mercury.

Dr. Backlund gives an accurate ephemeris of the comet from Nov. 8, 1894, to March 21, 1895, from which we extract that which will be of use to our readers in December and January. It is stated that Dr. Backlund is no longer to keep up the calculations for this comet.

Berlin Midn. 1894		α App. h	m	s	δ App. °	′	″	log r.	log Δ.	Aber. m	s
Dec.	10	22	20	21.19	+ 5	51	03.6	0.08651	9.95460	7	28.5
	11		19	52.63	5	42	30.0	08324	95413		28.1
	12		19	25.94	5	34	08.3	07777	95356		27.5
	13		19	01.02	5	25	57.8	07220	95288		26.8
	14		18	37.75	5	17	57.7	06652	95211		26.0
	15		18	16.04	5	10	07.3	06072	95126		25.1
	16		17	55.77	5	02	25.7	05481	95031		24.1
	17		17	36.83	4	54	52.1	04877	94926		23.1
	18		17	19.11	4	47	25.7	04261	94812		21.9
	19		17	02.50	4	40	05.5	03632	94688		20.7
	20		16	46.82	4	32	50.6	02990	94556		19.3
	21		16	31.98	4	25	39.9	02334	94406		17.8
	22		16	17.82	4	18	32.0	01663	94245		16.2
	23		16	04.17	4	11	25.5	00976	94071		14.5
	24		15	50.85	4	04	19.0	0.00274	93884		12.6
	25		15	37.74	3	57	10.8	9.99556	93683		10.7
	26		15	24.59	3	49	59.2	98821	93469		08.5
	27		15	11.21	3	42	42.4	98067	93242		06.2
	28		14	57.30	3	35	18.2	97295	92999		03.8
	29		14	42.65	3	27	44.3	96505	92741		01.3
	30		14	27.09	3	19	58.3	95695	92465		58.6
	31		14	10.57	3	11	57.3	94864	92170		55.8
	1895										
Jan.	1		13	52.25	3	03	38.3	94011	91860		52.9
	2		13	32.00	3	54	57.6	93135	91534		49.8
	3		13	09.58	2	45	51.9	92236	91189		46.6
	4		12	44.47	2	36	16.8	91313	90826		43.2
	5		12	16.27	2	26	07.9	90365	90444		39.6
	6		11	44.50	2	15	19.9	89389	90041		35.9
	7		11	08.66	2	03	47.2	88385	89619		32.1
	8		10	28.14	1	51	23.5	87352	89176		28.1
	9		09	42.38	1	38	01.8	86290	88714		24.0
	10		08	50.57	1	23	34.4	85196	88232		19.8
	11		07	52.00	1	07	53.0	84070	87731		15.4
	12		06	45.85	0	50	48.3	82909	87210		11.0
	13		05	31.27	0	32	10.9	81714	86671		06.4
	14		04	07.47	+ 0	11	47.6	80484	86114	6	01.7
	15		02	32.99	− 0	10	34.6	79218	85541	5	57.0
	16	22	00	46.48	0	35	08.8	77914	84954		52.2
	17	21	58	47.06	1	02	10.6	76572	84356		47.4
	18		56	33.25	1	31	56.1	75193	83750		42.6
	19		54	03.62	2	04	42.1	73777	83140		37.8
	20		51	16.65	2	40	47.3	72327	82534		33.1
	21		48	10.83	3	20	29.6	70843	81938		28.5
	22		44	44.70	4	04	06.6	69331	81364		24.2
	23		40	57.10	4	51	53.7	67793	80819		20.2
	24		36	46.71	5	44	04.2	66240	80319		16.5
	25		32	13.20	6	40	45.2	64679	79878		13.3
	26		27	16.53	7	41	56.9	63126	79517		10.7
	27		21	57.43	8	47	28.4	61597	79249		08.8
	28	21	16	18.12	− 9	56	56.7	9.60107	9.79105	5	07.8

Discovery of a New Comet.—A very faint comet was discovered by Edward Swift in California Nov. 20.500 in R. A. $22^h\ 18^m\ 24^s$, Decl. $-13°\ 07'$. Its motion is slow easterly. It is in the constellation Aquarius.

The next return of Comet 1884 II (Barnard).—In *Astronomische Nachrichten* No. 3260 Dr. Berberich gives the following elements of this comet for the epoch 1895, Feb. 9.0, Berlin mean time:

M	$= 339°\ 07'\ 39''.3$		
ω	$= 300\ 58\ 44\ .6$	ω	$= 300\ 58\ 55.3$
Ω	$= 5\ 13\ 01\ .4$ 1890.0	Ω	$= 5\ 21\ 13.2$ 1900.0
i	$= 5\ 27\ 35\ .7$	i	$= 5\ 27\ 40.3$
φ	$= 35\ 42\ 44\ .7$		
μ	$= 656''.252$		
$\log a$	$= 0.488624$		

Perihelion passage June 3.5 Berlin M. T.

The time of perihelion passage is uncertain by about ± 8 days. Dr. Berberich gives a search ephemeris extending from April 24 to July 5. The theoretical brightness of the comet in May, 1895, will be about twice that which it possessed when last seen in 1884, the maximum being reached in June.

NEWS AND NOTES.

We have sold this publication to the University of Chicago and the transfer of it will be made during this month. Our connection with it will therefore cease with this issue. Elsewhere will be found full directions as to the continuance of an astronomical journal under another name. Friends indebted to us will greatly oblige us by prompt settlement of dues. Those whose paid subscriptions do not expire with this month will be carried over to the new publication to the time of expiration unless subscribers so affected prefer to have their money refunded. We would however urge all to give hearty support to the ASTRO-PHYSICAL JOURNAL that its standard may be maintained. In our judgment there is not sufficient support for two journals of the grade of ASTRONOMY AND ASTRO-PHYSICS in this country. For this reason we have urged that the two publications be kept as one though the name and management be changed. Our sole object in the transfer has been to do that which is best for astronomy in general. In this we may be mistaken though we believe not.

Popular Astronomy will be continued as heretofore, and all readers interested in an untechnical and an unprofessional publication in the interest of astronomy are especially asked to favor this publication with their support.

Astronomy and Astro-Physics.—Complete volumes of this publication for the years 1892, 1893 and 1894 can be furnished by the publisher, W. W. Payne, in pamphlet form at the regular price of $4 each. There are only a few complete sets remaining.

To complete sets the publisher desires to purchase twenty copies of number 121, January 1894. Fifty cents each will be paid for so many copies in good condition sent to us during this month.

The Perseid Radiant.—Mr. Monck appears to think that a practical acquanitance with the details of meteoric observations does not enable a man to derive correct inferences from them, but that any outsider with a little theory or logic can treat them more successfully. He is entirely wrong, for the observer himself must necessarily possess a great advantage in arranging his results since he knows many particulars regarding the radiants, the weight to be attached to each one and other facts which will help him to avoid complications and errors.

Mr. Monck is singularly unfortunate in quoting Mr. Milligan's results in support of his views, for the latter derives his radeant points by rough estimation; he does not record the individual meteor paths but solely relies on his memory in retaining their directions and fixing their radiants. He saves trouble, no doubt, by dispensing with the use of charts or a celestial globe, but observations by the mental process can possess no value whatever. From the nature of them they must be very inaccurate and uncertain. Meteoric observations, if not made with the most extreme care and with some regard to a legitimate method, must necessarily lead the observer into a perfect labarynth of difficultics.

From theoretical considerations Le Verrier indicated, nearly a generation ago, that the Perseid radiant ought to exhibit a displacement of position when observed on different nights. In 1877, though not aware of Le Verrier's conclusion, I observed this displacement in a manner not to be mistaken In 1890 Kleiber demonstrated the significant agreement between the observed and computed radiants. In cases such as these where the mathematician and observer are in mutual accord there is really not much room left for caviling.

Apart from his strenuous efforts to prove I am incapable of identifying a meteor shower when I see it, Mr. Monck has severely criticised, in a former letter to ASTRONOMY AND ASTRO-PHYSICS, Professor Herschel's list of cometary and meteoric accordances. He has also questioned and spoken very lightly of the late Joseph Kleiber's mathematical treatment of the Perseid radiants and pointedly says "it was based on an assumption as to the shape of the meteor swarm which appears to have been suggested to Kleiber by Mr. Denning's supposed discovery." Mr. Monck is obviously not justified in making a statement of this kind with regard to the masterly analysis of Klieber, which he is neither able to disprove or confirm. He has indeed quite misapprehended the conclusive nature of the theoretical deductions and of the observations on which they rest It is however a consolation to reflect that impediments of the sort furnished by Mr. Monck must, in the ordinary course of things, be swept on one side only to form, in the years to come, the memorials of disappointed ambitions W. F. DENNING.

The Chicago Academy of Sciences.—*Section of Mathematics, Astronomy and Physics, November 12.*—The regular monthly meeting was held at the Commerce Club, in joint session with the section of Geology; Professor G. W. Hough, President, in the Chair.

After the transaction of routine business, the President introduced the speaker of the evening, Professor T. C. Chamberlain, who presented a most interesting illustrated lecture on "*Glacial Studies in Greenland.*" The speaker had accompanied the recent Peary party, and had obtained much valuable scientific data bearing upon the Glacial Theories. He sketched the somewhat perilous incidents of the journey, and gave a lucid explanation of the points of interest to geologists and astronomers. The illustrations were abundant and very excellent and illustrated every phase of glacier development. The speaker pointed out the difficulties of explaining the ice age, and of accounting for the extensive glaciation in North America. Professor Chamberlain thought his observations showed that the glaciers in Greenland had never been connected with those on the Continent, and that at several points in Greenland the current theories were erroneous; the sharp-topped mountains showed they had never been glaciated, though glaciation has hitherto been assumed to have taken place over the whole region. At the close of the lecture the speaker was warmly applauded, and on motion given a vote of thanks for his interesting paper. A general discussion of the possible astronomical causes of the ice age was then participated in by Professor Hough, Professor Chamberlain, Mr. Walker, and others, after which the meeting adjourned. 6.

GENERAL INDEX TO VOLUME XIII.

Aberration and atmospheric refraction of light,—Results of an investigation of, made with a modified form of the Loewy prism apparatus, G. C. Comstock 329
Constant of— 258
Chromatic—of telescopes, James E. Keeler (note) 157
The constant of— (note) 258
Abney, Photographic investigations of Captain—(note) 241
Captain, W. de W., C. B., R. E., D. C. L., F. R. S., President of the Royal Astronomical Society on presenting the gold medal to Mr. S. W. Burnham,—Address by 283
Academy of Sciences at Chicago, section of Mathematics and Astronomy, Meeting of the—Dec. 5, 1894, 87; Jan. 3, 1894, 173; Feb. 6, 1894, 262; March 5, 1894, 326; April 9, 1894, 419; May 14, 1894, 518; June 11, 1894, 602; Sept. 4, 1894 ..... 708, 782, 872
Royal Irish,—Transactions of—(note) 779
of Sciences at New York, Meeting of the— 88, 415
Achromatic object-glass, A new triple—(note) 400, 697
Address delivered by the President of the Royal Astronomical Society, Captain W. de W. Abney, C. B., R. E., D. C. L., F. R. S., on presenting the gold medal to Mr. S. W. Burnham 283
Adjustment of the equatorial, Quick—(note) 171
Agricultural College Observatory of Brookings, S. D., Observations of the transit of Mercury Nov. 10, 1894—(note) 868
Air, Refractive index of liquid—(note) 64
Algebra, Exercise book in—by M. S. Mc Curdy (notice) 788
Algol, Eccentricity of the orbit of the companion of—(note) 516
type of variable stars. (See variable stars)
variable, erratum 786
Altitude, Variation of gravity with—(note) 404
Apparatus for electrical control of telescope. (frontispiece) 265
Apparent orbits of binary stars, A graphical method of determining the—Charles P. Howard 425
Application to metrology of light waves, A. A. Michelson 92
Analyse der Gestirne, Scheiner's spectral—(note) 596
Annular eclipse of the Sun, April 5th, 1894 250
Anderson's variable in Andromeda (note) 317
Andromeda, Anderson's variable in—(note) 317
Arago medal for Professors Hall and Barnard (note) 81
Argentine Observatory, The National—John M. Thome 8
9 Argus, Note relative to β 101—(note) 518
Orbit of—S. W. Burnham 290

Arizona, An astronomical expedition from Harvard College Observatory to—(note) 316
Atmosphere of the Sun, Is there oxygen in the—J. Janssen (note) 238; N. C. Dunér 215
On Brester's views as to the tranquillity of the—Egon von Oppolzer 581
Atmospheric pressures, of the United States,—The polar radiation from the Sun, and its influence in forming the high and low—F. H. Bigelow 25
Asteroids, A photograph of the Pleiades and two—H. C. Wilson 192
1893, Numeration of— 254
Asteroid, 1893, AO, Discovery of new—(note) 79
1893, AP, Discovery of new— 168
1894, AQ, AR, and AS, Discovery of new— 254
1894, AT, AU, AV, AW, AX, AY, AZ, Discovery of new— 323
Astigmatism of Rowland's concave gratings, On the—J. L. Sirks 763
Astrolabe, Margaret L. Huggins 793
Astronomical instruments, Electric control and governor for—F. L. O. Wadsworth 265
Observatory of Harvard College, Vol. XXV (note) 171
photographs, Reproduction of—(note) 315
expedition to Arizona from Harvard College Observatory (note) 316
photographs, A collection of—G. E. Hale (note) 693
photography, The progress of—(note) 699
(note) 783
publications I, W. W. Payne 23
and Physical Society of Toronto, Canada, Meetings of—Dec. 1893, 174; Jan. 1894, 262; Feb. 1894, 327; March 1894 418
Report of meeting 786
Astronomy, Mathematics and—in the University of Chicago (note) 601
Meteoric—III. D. Kirkwood 188
and geology—Untrodden ground in—(note) 325
The bibliography of—(note) 261; (note) 519; (note) 603
The Dawn of—(note) 259
Astrophysical journal, The—Geo. E. Hale 831
Atmospheric refraction of light, made with a modified form of Leowy prism apparatus, Results of an investigation of the aberration and—Geo. C. Comstock 329
Auriga, On the new star in—H. C. Vogel, 48; (notes) 66; 136; H. Seeliger 142
Aurigæ, Nova—E. E. Barnard (note) 598
Professor Vogel on Nova—(note) 150
Change in the brightness of Nova—(note) 156
Nova—and Nova Normæ, A study of—W. H. Pickering 201
On the visual appearance of Nova—William Huggins 314
Note on Nova—M. Brendel, (note) 315
Auroræ, Height of—J. A. Copland (note) 506
and solar prominences, M. A. Veeder (note) 597
Aurora observations, North Greenland—(note) 779
International cipher code for—(note) 170
of March 30, 1894, J. W. Johnson and M. A. Veeder (note) 401
Auxilliary quantities for computing precession, (note) 87

Ball bearings, A simple method of mounting an equatorial axis on—F. L. O. Wadsworth 723
Barnard, E. E., Proper motion of stars in dumb-bell nebula 445
Preliminary note on the observations of Saturn and Uranus with the 36-inch equatorial 557
Photograph of Swift's nebula in Monoceros, N. G. C. 2237 642
Great red spot and other markings on Jupiter 736
Nova Aurigæ (note) 598
Tempel's periodic comet (note) 598
Recipient of the Arago gold medal (note) 81
Photographic nebulosities and star clusters connected with the milky way 177
On the forms of the discs of Jupiter's satellites as seen with the 36-inch equatorial of Lick Observatory 272
On the diameters of Ceres, Pallas and Vesta 341
Photographs of Gale's comet, 1894 421
Recent observations of Jupiter's satellites 438
Periodic time and distance of the fifth satellite of Jupiter 556
Present to the Royal Astronomical Society (note) 783
Photographs of a remarkable comet 789
Photograph of M8 and the Trifid nebula 791
On the exterior nebulosities of the Pleiades 768
Great photographic nebula of Orion encircling the belt and Theta nebula 811
The form of the disc of the III satellite and phenomena of the occultation of a satellite of Jupiter 821
Belopolsky, A., On the motion of ζ Hercules in the line of sight 130
Bessemer flame; Hartley's observation of *C* line of hydrogen in the—(note) 770
β 101, 9 Argus, Note relation to— 518
Bibliography of astronomy (notes) 261, 519, 603
Bigelow, Frank H., The polar radiation from the Sun, and its influence in forming the high and low atmospheric pressures of the United States 25
West Indian hurricanes and solar magnetic influence 441
Binary star OΣ 224, Orbit of—J. E. Gore 559
Binary stars, A graphical method of obtaining the orbits of—Charles P. Howard 425
Bolometer work at the Smithsonian Astro-Physical Observatory, Mr. Langley's recent progress in 41
Borst-Peters' star catalogue (note) 417
Brashear's new optical works (note) 700
Brester, A., Jz.—A short review of my theory of the Sun 218
On Brester's views as to the tranquillity of the solar atmosphere 849
Brightness of Nova Aurigæ, Change in the—(note) 156
British photographs of the recent total eclipse of the Sun (note) 83
Brorsen's Comet 1851 III (note) 787
Bulow, Dr. Friederick Gustav von—Obituary notice 112
Burckhalter, Chas.,—Discovery of Comet *b*, 1893 170
Burnham, S. W.,—Proper motions of double stars 14
gold medal for—(note) 169

Burnham, S. W., Address delivered by the president of Royal Astronomical Society, Captain W. de W. Abney, on presenting gold medal to— 283
The Pulkowa double star measures..... 354
The variable proper motion of Procyon..... 434
The orbit of 9 Argus..... 290
Camera, The advantage of the short-focus—in spectrum photography, J. E. Keeler (note)..... 772
Campbell, W. W., Observations of the new star in Norma..... 311
Spectra of the Great Nebula in Orion and other well-known nebulæ..... .....384, 494
The Wolf-Rayet stars..... 448
Note on the spectra of Comets *b* and *c*, 1893..... 571
spectrum of the Orion nebula (note)..... 695
The spectrum of Mars..... 752
On the accuracy of his measures in the spectrum of Nova Aurigæ (note)..... 69
The use of the short-focus camera in stellar spectrum photography (note)..... 857
On selecting suitable nights for observing planetary spectra (note)..... 860
Canada, Reports from—(notes)..... .....418, 518, 786
Canals of Mars, J. R. Holt..... 347
Cape observatory, A large telescope for the—(note)..... 770
Catalogue for 1885, Pulkowa—(note)..... 597
Catalogues of Harvard College Observatory, Photometric—(note)..... 598
Causes of formation, motion and periodicity of sunspots, Mechanical—J. M. Schaeberle..... 278
Centauri, α, Dr. Lee's researches on the orbit of—(note)..... 256
Center of gravity for a homogeneous ellipsoid of revolution, Locus of—T. J. J. See..... 627
Ceres, On the diameter of—Pallas and Vesta, E. E. Barnard..... 341
Chabot observatory, Observations of the transit of Mercury, Nov. 10, 1894 (note)..... 868
Chamberlin Observatory, 20-inch equatorial of—H. A. Howe.....709, 826
Chandler on observations of variable stars at Harvard College Observatory, (note)..... 325
Chandler's criticisms of the Harvard photometric observations (note) 399, 416
Change of sensitiveness in dry plates, The—G. W. Hough (note)..... 153
in the brightness of Nova Aurigæ (note)..... 156
Charroppin C. M., (note) 596; (note)..... 417
Chart of the Heavens, Photographic—*Observatory*, Dec., 1893..... 20
sky, Photographic—H. C. Wilson (note)..... 260
Chicago Academy of Sciences, Section of mathematics and astronomy (see Academy of Sciences at Chicago)..... 87
Meeting of—Jan. 3, 1894, T. J. J. See, 173; Feb. 4, 1894, 262; March, 1894, 326; April, 1894, 419; May, 1894, 518; June, 1894, 602; Sept., 1894, 708; Oct..... 782
Chromatic abberration of telescopes—James E. Keeler (note)..... 157
Chromosphere, The appearance of the D_3 line in the spectrum of the—(note)... 585

Chronograph, Electrical clock connections for operating the—G. W. Hough.... 184
Cipher code for aurora observations, An international—(note)..... 170
Clock connections for operatiug the chronograph, Electrical—G. W. Hough.... 184
Cluster in Hercules, The great—(note)..... 156
Coast survey office of the United States (note)..... 414
C line of hydrogen in the Bessemer flame, Hartley's observations of the—(note)..... 770
Code for Aurora observations, International cipher—(note)..... 170
Cometary shooting stars, H. A. Newton..... 196
structure in the corona of April 16, 1893, J. M. Schaeberle..... 307
Comets, note on the spectra of—H. Kayser..... 204
for 1894 (note)..... 72
Comet spectra, on the influence of the slit-width on the appearance of—367; (note) 505; H. Kayser (note)..... 399
b and *c* 1893, note on the spectra of—W. W. Campbell..... 571
b 1894 (Gale), the spectrum of—(note)..... 504
spectra, The nature of—..... 586
b 1893, discovery of—(note)..... 170
c 1893 (Brooks), ephemeris of—for Jan., 1894, Wendell, 80; March, 1894..... 255
a 1894, discovery of new—by Denning, 323; (notes).....410, 511
(Denning) ephemeris of—(note) 514; elliptic elements of—(note)..... 515
b 1894 (Gale)—(notes) 411; 512; ephemeris of—(note)..... 513
Gale's—1894, May 3, frontispiece, 421; photograph of—E. E. Barnard 421
Gale's—(note)..... 514
Brorsen's—1851, III (note)..... 787
Photographs of a remarkable—E. E. Barnard..... 789
discovered in Australia new—(note)..... 410
(1873 II) ephemeris of Tempel's second periodic—(note)..... 411
Halley's—(note)..... 352
of Holmes, search for—(note)..... 324
in the corona of April 16, 1893—(note)..... 515
notes for May, 1894, 410; June, 1894, 511; October, 1894..... 706
medals—(note)..... 518
Tempel's periodic—(notes).....514, 598
Tempel, II 1894, III (1873, II), new elements of—(note)..... 706
1894 II (Barnard), The next return of—[note]..... 871
notes..... 869
Comet's tail—discovered by Holmes (note)..... 410
Companion of Sirius, Orbit of—(note)..... 82
to Algol, Eccentricity of the orbit of—(note)..... 516
Computing precession, Auxilliary quantities for—(note)..... 87
Comstock, G. C., Results of an investigation of the aberration and atmospheric refraction of light, made with a modified form of the Leowy prism apparatus..... 329
George C., Note relative to β 101, 9 Argus..... 518
Concave gratings, On the astigmatism of Rowland's—J. L. Sirks..... 763
Control for the equatorial, Electric—G. W. Hough..... 524
of equatorials in photography, Electric—W. C. Gurley..... 641
Contents for January 1894, 176; February 1894, 264; March 1894, 328; April 1894, 420; May 1884, 520; June 1894..... 604

Constant of aberration (note)..... 258
Constitution of the planet Jupiter, Physical—G. W. Hough..... 89
Controls and governors for astronomical instruments, Electric—F. L. O. Wadsworth..... 265
Copland, John A., Height of Auroræ (note)..... 506
Dec. 1893, Meeting of the A. and P. S. of Toronto—..... 175
Jan. 1894, same..... 262
Cornu, A., A study of diffraction gratings, Focal anomalies—..... 207
Corona of the total solar eclipse April 16, 1893, Professor Shaeberle's photographs of—(note)..... 169
of the total solar eclipse of April 16, 1893, Cometary structure in—J. M. Schaeberle..... 307
On some attempts to photograph the solar—without an eclipse, Geo. E. Hale..... 662
Cornu's spectroscopic investigations, Monsieur—G. E. Hale (note)..... 57
Crew, Henry and Robert Tatnall, On a new method for mapping the spectra of metals..... 741
Cygnus, 61, Motion of—(note)..... 84
Czapski, Theory of optical instruments by Dr.—(note)..... 241
Davidson observatory transit of Mercury, Nov. 10, 1894 [note]..... 866
Dawn of astronomy (note)..... 259
Determination of stellar motions, Photographic—E. C. Pickering..... 521
Denning, W. F., New comet discovered by—..... 323
The radiant of the August Perseids (note)..... 600
The Perseid radiant [note]..... 872
Device for securing Mercury's surface undisturbed by Earth tremors (note)..... 597
Diameters of Ceres, Pallas and Vesta, E. E. Barnard..... 341
Diffraction gratings, A study of—Focal anomalies—A Cornu..... 207
Discovery of new comet (see comet)
asteroid (see asteroid)
Disc of III satellite and phenomena of the occultation of Jupiter's satellites E. E. Barnard..... 821
Discs of Jupiter's satellites, as seen with the 36-inch equatorial of the Lick Observatory, E. E. Barnard..... 272
The form of—W. H. Pickering..... 423
The shape of—(note)..... 517
Dispersion of fluorite and rock-salt, (note)..... 772
Distance of Jupiter's fifth satellite, Periodic time and—E. E. Barnard..... 556
Distribution of the heat of the Sun, W. H. S. Monck..... 823
D_3 line, Observations of a solar prominence and reversal of the—W. E. Woods (note)..... 159
in the spectrum of the chromosphere, The appearance of the—(note)... 585
Domes and telescope mountings, W. H. Pickering..... 1
Double motion mechanism, Some new forms of—F. L. O. Wadsworth..... 527
star measures in 1892, by Professor Glassenapp (note)..... 516
stars, Proper motion of--S. W. Burnham..... 14
star measures, The Pulkowa—S. W. Burnham..... 354
star apparently new, R. D. Sprague (note)..... 417
star near H 3950 (note)..... 516
Douglass A. E., The polar cap of Mars..... 738
Dry plates, The change of sensitiveness in—Geo. W. Hough (note)..... 153

XUM

Dumb-bell nebula, Proper motion of stars in—E. E. Barnard..... 445
Duner, N. C., Is there oxygen in the atmosphere of the Sun?..... 215
Earth tremors, A device for securing a Mercury surface undisturbed from—(note)..... 597
Eccentricity of the orbit of the companion of Algol (note)..... 516
Eclipse of Sun April 5, 1894, Annular—..... 250
of the Moon, Partial—March 21, 1894, 165; Sept. 14, 1894..... 594
Observations of—..... 705
of the Sun, Total—..... 595
of the Sun, The British photographs of the recent total—(note)..... 82
On some attempts to photograph the solar corona without an eclipse, Geo. E. Hale..... 662
Professor Schaeberle's photographs of the corona of the total solar—April 16, 1893 (note)..... 169
Eclipses for the year 1894, H. C. Wilson (note)..... 70
Effective temperature of the Sun, Experimental investigations on the—W. E. Wilson and P. L. Gray..... 382
Electric controls and governors of astronomical instruments, F. L. O. Wadsworth..... 265
Electrical clock connections for operating the chronograph, G. W. Hough..... 184
control for the equatorial, G. W. Hough..... 524
control of telescope, Apparatus for—(frontispiece)..... 265
control of equatorials in photography, W. C. Gurley..... 641
Elements, On a certain law in the spectra of some of the—C. Runge..... 124
Elkin, W. L., Instrument for the photography of meteors..... 628
Ellipsoid of revolution, Locus of the center of gravity for a homogeneous—T. J. J. See..... 627
Encke's comet, Ephemeris of—by Buckland..... 870
Rediscovery of—[note]..... 871
Equatorial axis, Method of mounting an—on ball bearings, F. L. Wadsworth 723
Electrical control for—G. W. Hough (frontispiece)..... 521
Electric control for—G. W. Hough..... 524
Electrical control of—in photography, W. C. Gurley..... 641
of Chamberlin Observatory, 20-inch—H. A. Howe.....709, 826
Quick adjustment of—(note)..... 171
Equatorials in photography, electrical control of—W. C. Gurley..... 641
Errata (notes).....419, 788
Hartwig's Algol variable (note)..... 786
in photograph of Gale's comet (note)..... 706
in the August number (note)..... 700
Disk of Jupiter's satellite..... 603
Espin, T. E., The spectrum of α Herculis..... 651
Experiments on the radiation of heated gases (note)..... 859
Extraordinary phenomena (note)..... 172
Exterior nebulosities of the Pleiades, On the—E. E. Barnard..... 768
Faculæ, The solar—G. E Hale..... 113
Fenyi, J., S. J, On two great protuberances..... 122
Ferry, E. S. and E. P. Lewis, The infra-red spectra of metals..... 747
Fixed-arm spectroscopes—F. L. O. Wadsworth..... 835
Fleming, M., Stars having peculiar spectra..... 501
Two new variable stars..... 195
Focal anomalies, A study of diffraction gratings, A. Cornu..... 207

Formation of sunspots, Mechanical causes—J. M. Schaeberle..... 278
Fluorite and rock-salt, The dispersion of—(note)..... 772
Forms of the discs of Jupiter's satellites, W. H. Pickering..... 423
Free public observatory, W. W. Payne..... 110
Frost, E. B., Unit of velocity in the line of sight, (note)..... 160
Frost's translation and revision of die Spectralanalyse der Gestirne, J. E. Keeler..... 688
Gale's Comet (*b*) 1894, May 3, (frontispiece)..... 421
Photographs of—E. E. Barnard..... 421
May 5th, $8^h\ 45^m$ S. P. T. (facing)..... 560
Correction in the photograph of—(note)..... 706
Ephemeris of—(note)..... 513
(note)..... 512
Gases, The radiation of heated—Robert R. Tatnall (note)..... 153
(note)..... 587
Experiments on the radiation of heated—(note)..... 859
Geology and astronomy, Untrodden ground in (notice)..... 325
Geometry, Solid—by A. L. Baker (note)..... 188
Glazebrook's light (note)..... 402
Glassenapp's double star measures in 1892 (note)..... 516
Gold medal for Professor Burnham (note)..... 169
Address on presenting—to Professor Burnham by President Abney..... 283
Goodsell Observatory, Sunspot observations at—H. C. Wilson..... 293
Lantern slides at—(note)..... 342
Transit of Mercury, Nov. 10, 1894 [note]..... 866
Gothard, Eugen von, A small nebula at M57..... 190
Gore, J. E., Orbit of the binary star OΣ 224..... 559
Governors and electric controls for astronomical instruments, F. L. O. Wadsworth..... 265
Graphical method for binary star orbits, Charles P. Howard..... 425
Greenland Aurora Observations, North—(note)..... 779
Gratings, A study of diffraction—Focal anomalies, A. Cornu..... 207
On the astigmatism of Rowland's concave—J. L. Sirks..... 763
The object-glass—L. E. Jewell, 44; (note)..... 155
Gravity, Variations of—with altitude (note)..... 404
Gray, P. L., and W. E. Wilson, Experimental investigations on the effective temperature of the Sun..... 382
Great cluster in Hercules (note)..... 156
telescope, Another—(note)..... 700
nebula in Orion and other well-known nebulæ, Spectra of the—W. W. Campbell..... 494, 384
Note on the spectrum of the—William Huggins..... 568
On the photographic spectrum of the—J. Norman Lockyer..... 574
Dr. Huggins' 1888 photograph of the spectrum of the—G. E. Hale (note)..... 696
red-spot on Jupiter (see Jupiter)
Greenwich Observatory, New telescope for—(note)..... 317
Gurley, W, C., Electric control of equatorials in photography..... 641
Hadden's solar work (note)..... 316
Hale, Professor George E., (note)..... 596
Monsieur Cornu's spectroscopic investigations (note)..... 57

Spectroscopy at Stonyhurst College Observatory (note)..... 58
New nomenclature for the hydrogen series (note)..... 63
Spectroheliograph for the Yerkes telescope (note)..... 64
The solar faculæ..... 113
The spectroscopic investigations of Mr. George Higgs (note)..... 151
On some attempts to photograph the solar corona without an eclipse... 662
A collection of astronomical photographs (note)..... 693
Dr. Huggins' 1888 photograph of the spectrum of the great nebula in Orion (note)..... 696
Hale, Geo. E., The Astrophysical journal..... 831
Hall, Professor A., recipient of the Arago medal (note)..... 81
Halley's comet (note)..... 325
Halsted observatory observations of the transit of Mercury, Nov. 10, 1894 by C. A. Young [note]..... 868
Harkness Professor W., On the magnitude of the solar system..... 605
Harvard College Observatory, An astronomical expedition to Arizona from—(note)..... 316
Photometric observations, Dr. Chandler's criticisms of the—(note)..... 399, 416
Photometric catalogues (note)..... 586, 598
Volume XXV of the astronomical observatory of—(note)..... 171
Hartley's observations of the *C* line of hydrogen in the Bessemer flame (note) 770
Hartwig's Algol variable, error (note)..... 786
Hasselberg, B., On the line spectrum of oxygen..... 760
Researches on the spectra of metals by Professor—(note)..... 585
Hazen, H. A., West Indian hurricanes and solar magnetic influence..... 105, 443
Heat, The temperature of the surface of the fixed stars and of the Sun, compared with that of terrestrial sources of—J. Scheiner..... 856
of the Sun, Distribution of the—W. H. S. Monck..... 329
Heated gases, The radiation of—Robert R. Tatnall (notes)..... 153, 587
Heavens, Photographic chart of the—*Observatory*, Dec. 1893..... 20
Height of Auroræ, J. A. Copland (note)..... 506
Herbert, Hon. H. A., Nautical office investigation (note)..... 414
Herculis, ζ, On the motion of—in the line of sight, A. Belopolsky..... 130
The great cluster in—(note)..... 156
α, The spectrum of—T. E. Espin..... 651
Higgs, The spectroscopic investigation of—Mr. George; G. E. Hale (note)..... 151
Hill, Geo. A., A search for comet Holmes (note)..... 324
Hill, Chas. B., observations of the transit of Mercury, Nov. 10, 1894, [note] 867
Holden, Edward S., Recent observations of Jupiter's satellites..... 356
Discovery of comet *b*, 1893 (note)..... 170
Holmes' comet, A search for—(note)..... 324
Holt, J. R., The canals of Mars..... 347
Homogeneous Ellipsoid of revolution, Locus for the center of gravity for a—T. J. J. See..... 627
Hough, G. W., On the physical constitution of the planet Jupiter..... 89
Electrical clock connections for operating the chronograph..... 184
An electrical control for the equatorial (frontispiece)..... 521
Electric control for the equatorial..... 524
The change of sensitiveness in dry plates (note)..... 153
Howard, Charles P., A graphical method for determining the apparent orbits of binary stars..... 425

Orbit of the companion of Sirius (note)..... 82
Howe, H. A., The 20-inch equatorial of Chamberlin Observatory.....709, 826
Hurricanes and solar magnetic influences, West India—H. A. Hazen.....105, 443
Same, Frank H. Bigelow..... 441
Huggins, Margaret L., The Astrolabe..... 793
William, On the visual appearance of Nova Aurigæ..... 314
Note on the spectrum of the great nebula in Orion..... 568
Mars (note)..... 771
Huggins' 1888 photograph of the spectrum of the great nebula in Orion, G. E. Hale (note)..... 696
Hutchins, C. C., Platinum on glass mirrors (note)..... 858
Hydrogen series, New nomenclature for the—G. E. Hale (note)..... 63
in the Bessemer flame, Hartley's observation of the *C* line of—(note). 770
Illinois Wesleyan University, Telescope for—(note)..... 784
Infra-red spectra of metals, The—E P. Lewis and E. S. Ferrys..... 747
International cipher code for aurora observations (note)..... 170
Instrument for the photography of meteors, W. L. Elkin..... 626
Investigation of the aberration and atmospheric refraction of light made with a modified form of the Loewy prism apparatus, Results of—G. C. Comstock..... 329
Irish Academy, Transactions of the Royal—(note)..... 779
Jacoby Harold, Report of Dec. 1893 meeting of the N. Y. Academy of sciences 88
Janssen, Jules, Is there oxygen in the atmosphere of the Sun (note)..... 238
Jupiter's great red spot, Approximate time of passing the central meridian of February 1894, 79; March 1894, 162; April 1894..... 247
and other markings, E. E. Barnard..... 736
III satellite, The form of the disc of—and phenomena of the occulta- of a satellite of Jupiter, E. E. Barnard..... 821
fifth satellite, Periodic time and distance of—E. E. Barnard..... 556
first satellite, Disc of—(note)..... 603
fifth satellite, Orbit of—(note)..... 781
satellites for February 1894, 77; March 1894, 163; April 1894, 248; December 1894..... 775
satellites, Phenomena of—for February 1894, 78; March 1894, 164; April 1894, 249; December 1894..... 776
satellites, On the forms of the discs of—as seen with the 36-inch equatorial of the Lick Observatory, E. E. Barnard..... 272
Recent observations of—Edward S Holden..... 356
Forms of the discs of—W. H. Pickering..... 423
Recent observations of—E. E. Barnard..... 438
Shape of the discs of—(note)..... 517
Recent observations of—W. H. Pickering..... 728
Jupiter, Physical constitution of the planet—G. W. Hough..... 89
The mass of—(note)..... 786
Jewell, L. E., The object-glass grating.....44, 155
Johnson, John W., The aurora of March 30, 1894 (note)..... 401
Kayser, Professor, at Bonn (note)..... 505
H., note on the spectra of comets..... 204
On the influence of the slit-width on the appearance of comet spectra. 367
Keeler, James E., Professor Lockyer's researches on stellar spectra..... 59
Chromatic aberration of telescopes (note)..... 157

On the spectra of the Orion nebula and the Orion stars..... 476
The magnesium spectrum as an index to the temperature of the stars.. 660
The use of the short-focus camera in stellar spectrum photography (note)..... 858
Professor Frost's translation and revision of die spectralanalyse der gestirne..... 688
The advantage of the short-focus camera in spectrum photography (note)..... 772
The rise of the short-focus camera in stellar spectrum photography (note)..... 858
Kirkwood Daniel, Meteoric astronomy III..... 188
Lacus Solis on Mars, Region of—J. M. Schaeberle..... 644
Latest views regarding Mars, Schiaparelli's—W. H. Pickering..... 632
Langley's recent progress in bolometer work at the Smithsonian Astrophysical Observatory..... 41
Lantern slides at Goodsell Observatory (note)..... 324
Large telescope for the Cape Observatory, A—(note)..... 770
Lenses, Large rock-salt prism and—(note)..... 240
Leander McCormick Observatory, Observations of the transit of Mercury, Nov. 10, 1894 (note)..... 863
Leavenworth, F. P., A device for keeping Mercury surface steady (note)..... 598
Lewis, E. P. and E. S. Ferry, The infra-red spectra of metals..... 747
Lick Observatory, New star spectroscope for the—(note)..... 401
On the forms of the discs of the satellites of Jupiter as seen with the 36-inch equatorial of—E. E. Barnard..... 272
Publications of—Vol. II, 1894, (note) 416; Vol. III 1894, (note)..... 784
Lightning, An object-glass struck by—(note)..... 700
Light waves and their application to meteorology, A. A. Michelson..... 92
Glazebrook's—(note)..... 402
Line of sight, On the motion of ζ Herculis in the—A. Belopolsky..... 130
Unit of velocity in the—E. B. Frost (note)..... 160
Line spectrum of oxygen (note)..... 505
B. Hasselberg..... 760
Liquid air, Refractive index of—(note)..... 64
Lockyer, J. Norman, On the photographic spectrum of the great nebula in Orion..... 574
The spectrum changes in β Lyræ. Preliminary note..... 575
Lockyer's researches on stellar spectra, J. E. Keeler (note)..... 59
Locus of center of gravity for a homogeneous ellipsoid of revolution. T. J. J. See..... 627
Loewy prism, Results of an investigation of the aberration and atmospheric refraction made with a modified form of—G. C. Comstock.... 329
Long focus telescopes, William Rollins..... 199
Lowell, Percival, Mars.....538, 645, 740, 814
Lowell Observatory (note)..... 402
Transit of Mercury, Nov. 10, 1894 (note)..... 865
Lumsden, Mr. G. E., Article in Canadian Magazine (note)..... 324
Lyræ β, on the spectrum of—H. C. Vogel.....358, 562
The spectrum changes in—J. Norman Lockyer..... 575
The spectrum of—(note)..... 584

Magnesium spectrum as an index to the temperature of the stars, J. E. Keeler 660
Magnetic influence, West Indian hurricanes and solar—H. A. Hazen.....105, 443
Same, Frank H. Bigelow 441
Magnitude of the solar system, Wm. Harkness 605
Manila, Philippine islands observatory at—(note) 85
Mapping the spectra of metals, On a new method for—Henry Crew and Robert Tatnall 741
Mars, Percival Lowell 538, 645, 740, 814
The planet, Giovanni Schiaparelli 714
The polar cap of—A. E. Douglas 738
Observations of—(note) 785
satellites for September and October, 1894 591; November, 1894 703
orbits, Nautical Almanac error in diagram of—(note) 707
Solar image reflected in the seas of—(note) 257
Melting of the polar caps of—W. H. Pickering 308
The canals of—J. R. Holt 347
The seas of—W. H. Pickering 553
Schiaparelli's map of—1888. Frontispiece 605
Schaparelli's latest views regarding—W. H. Pickering 632
Region of Lacus Solis on—J. M. Schaeberle 644
The spectrum of—W. W. Campbell 752
Note on—William Huggins (note) 771
Mass of Mercury (note) 781
Jupiter (note) 786
Mathematics and astronomy at the Chicago University (note) 601
Maxima and minima of variable stars (see variable stars).
Measures, The Poulkowa double star—S. W. Burnham 354
Medal for Professor Burnham, Gold—(note) 169
Address by the president of the Royal Astronomical Society on presentation of 283
Melting of the polar caps of Mars, W. H. Pickering 308
Mechanical causes of the formation, motion and periodicity of the sun-spots J. M. Schaeberle 278
Mechanism, Some new forms of double motion—F. L. O. Wadsworth 527
Mercury surface, A method for securing—undisturbed by earth tremors (note) 597
Mass of—(note) 781
Transit of—Nov. 10, 1894 (notes) 70, 704, 779
Transit of—Nov. 10, 1894, as observed at Lowell, Davidson, Chabot, Halsted, Agricultural College (Brookings, S. D.), Leander McCormick and Goodsell Observatories 865-869
M 8 and the trifid nebula, Photograph of—E. E. Barnard 791
Metals, Researches on the spectra of—by Professor Hasselberg (note) 585
On a new method for mapping the spectra of—Henry Crew and Robert Tatnall 741
The infra-red spectra of—E. P. Lewis and E. S. Ferry 747
Meridian circle work at Washington (note) 415
Meteorology, Light-waves and their application to—A. A. Michelson 92
Meteors, Instrument for the photography of—W. L. Elkin 626
Meteor, A brilliant—250; (note) 417
Meteoric astronomy III. Daniel Kirkwood 188
Method for determining the apparent orbits of binary stars, C. P. Howard 425

XUM

Metrology, Light waves and their application to—A. A. Michelson..... 92
Michelson, A. A., Light waves and their application to metrology..... 92
Milky Way, Photographic nebulosities and star clusters connected with the—
E. E. Barnard..... 177
Minima of variable stars of the Algol type (see variable stars).
Mirrors, Platinum on glass—C. C. Hutchins (note)..... 858
Moon, Eclipse of—(see eclipse).
(note) Map published by Poole Brothers..... 787
Monck, W. H. S., The Perseid radiant..... 344
The distribution of the heat of the Sun..... 823
Perseid radiant (note)..... 783
Monoceros, Photographs of Swift's nebula in—N. G. C. 2237—E. E. Barnard 642
Morse, Fremont, Observations of the transit of Mercury, Nov. 10, 1894
(note)..... 867
Motion of ζ Herculis in the line of sight, On the—A. Belopolsky..... 130
stars in the Dumb Bell nebula, Proper—E. E. Barnard..... 445
61 Cygni (note)..... 84
sun spots, Mechanical causes of—J. M. Schaeberle..... 278
Motions, Photographic determination of stellar—E. C. Pickering..... 521
Mounting an equatorial axis on ball bearings, A simple method of—F. L. O.
Wadsworth..... 723
Mountings of telescopes and domes—W. H. Pickering..... 1
Nautical Almanac, error in Mars' satellite orbits (note)..... 707
office investigation (note)..... 413
Naval observatory of the United States (note)..... 601
Reorganization of the—of the United States (note)..... 707
National Argentine observatory, J. M. Thome..... 8
Nature of comet spectra (note)..... 586
Nebula at M57, Small—Egon von Gothard..... 190
in Monoceros, Photograph of Swift's—N. G. C. 2237, E. E. Barnard... 642
Note on the spectrum of the Orion—W. W. Campbell (note)..... 695
in Orion, Dr. Huggins' 1888 photograph of the spectrum of the great—
G. E. Hale (note)..... 696
The great photographic—of Orion encircling the belt and Theta nebula. E. E Barnard..... 811
Proper motion of stars in dumb bell—E. E. Barnard..... 445
The trifid and M8—photographed, E. E. Barnard..... 791
The planetary—S D. — 12°, 1172 (note)..... 159
in Orion and other well-known nebulæ, Spectra of the great—W. W.
Campbell.....494, 384
On the spectra of the Orion—and the Orion stars, James E. Keeler..... 476
Red fringe to the Orion—(note)..... 504
in Orion, Note on the spectrum of the great—William Huggins..... 568
On the photographic spectrum of the great—J. Norman
Lockyer..... 574
Nebulosities of the Pleiades, On the exterior—E. E. Barnard..... 768
Nebulosities—Photographic—and star clusters connected with the milky way,
E. E. Barnard..... 177
Neptune, Satellites of—F. Tisserand..... 291
for December 1894..... 778
Newall, H. F., On a combination of prisms for stellar spectroscope..... 309
Newcomb, Professor S., Nautical office investigation (note)..... 413

New double star, Apparently—R. Sprague (note) 417
forms of double motion mechanism, F. L. O. Wadsworth 527
nomenclature for the hydrogen series, Geo. E. Hale (note) 63
Observatories (note) 586
scientific terms wanted (note) 63
star in Norma, A—E. C. Pickering 40, 398
Observations of the—W. W. Campbell 311
Auriga, On the—H. C. Vogel 48; (notes) 66, 136; H. Seeliger 146
Newton, H. A., Cometary shooting stars 192
News and Notes for January 1894, 80; February 1894, 196; March 1894, 256; April 1894, 323; May 1894, 413; June 1894, 516; August 1894, 596; October 1894, 706; November 1894, 779; December, 1894 871
New stars (note) 63
variable stars, Two—M. Fleming, 195; (note) 63
Star (note) 159
New York academy of sciences Dec. (1893), Meeting, 88; March (1894) 415
Nights for observing planetary spectra, On selecting suitable—W. W. Campbell (note) .....
Nomenclature, New, for the hydrogen series—G. E. Hale (note) 63
Norma, A new star in—E. C. Pickering 40, 398
A study of Nova Aurigæ and Nova—W. H. Pickering 201
Observations of the new star in—W. W. Campbell 311
Notes on stellar spectra (note) 158
the spectra of comets—H. Kayser 204
Note on the spectrum of the great nebula in Orion—William Huggins 568
spectra of comets *b* and *c* 1893—W. W. Campbell 571
spectrum of the Orion nebula—W. W. Campbell (note) 695
Mars—William Huggins (note) 771
Nova Aurigæ (note) 598
Mr. Campbell on the accuracy of his measures in the spectrum of—(note) 66
Professor Vogel, on—(note) 150
Change in the brightness of—(note) 156
and Nova Normæ, A study of—W. H. Pickering 201
On the visual appearance of—William Huggins 314
Note on—M. Brendel (note) 315
E. E. Barnard (note) 598
Nova Normæ, A study of Nova Aurigæ and—W. H. Pickering 201
Obituary notices, Drs. Rudolf Wolf and Adolph Steinheil and Frederick Gustav von Bulow 112
Object-glass grating, The—L. E. Jewell 44; (note) 155
A new triple achromatic—(notes) 400, 696
struck by lightning (note) 700
Observations of Jupiter's satellites, Recent—E. S Holden 356; E. E. Barnard 438; and W. H. Pickering 728
An international cipher code for aurora—(note) 170
North Greenland aurora—(note) 779
of Mars (note) 785
of Saturn and Uranus with 36-inch equatorial, Preliminary note on—E. E. Barnard 557

of a solar prominence, and reversal of the D_3 line, W. E. Woods (note) 159
of the *C* line of hydrogen in the Bessemer flame, Hartley's—(note) 770
made at the Roman College in 1893, Solar—P. Tacchini (note). 244
of the new star in Norma, W. W. Campbell 311
made at the Roman College during the fourth quarter of 1893, P. Tacchini, third and fourth 1893, 503; first 1894 (note..... 588
Observatories, Free public—W. W. Payne 110
New—(note) 586
Observatory, Dec., 1893, Photographic chart of the heavens 20
Observatory, The National Argentine—John M. Thome 8
Photographic telescope of Potsdam—(note) 81
at Manila, Phllippine Islands (note) 85
Sun spot observations at Goodsell—H. C. Wilson 293
United States Naval—(note) 601
Reorganization of—(note) 707
20-inch equatorial of Chamberlin—H. A. Howe 709
On the forms of the discs of Jupiter's satellites as seen by 36-inch equatorial of Lick—E. E. Barnard 272
Yale, Instrument for photographing meteors for—W. L. Elkin.. 626
The 20-inch equatorial for Chamberlin—H. A. Howe,.....709, 826
Observing planetary spectra, On selecting suitable nights for—W. W. Campbell (note) 860
Occultation of a satellite of Jupiter and the form of the disc of the III satellite. E. E. Barnard 821
Occultations visible at Washington for February, 1894, 77; (note) 70; March, 1894, 166; April, 1894, 254; June, 1894, 406; July and August, 1894, 509; September and October, 1894, 593; November, 1894, 703; December, 1894 774
On a certain law in the spectra of some of the elements, C. Runge 128
the motion of ζ Herculis in the line of sight, A. Belopolsky 130
a combination of prisms for stellar spectroscope, H. F. Newall 309
the spectra of the Orion nebula and the Orion stars, James E. Keeler..... 476
the photographic spectrum of the great nebula in Orion, J. Norman Lockyer 574
Brester's views as to the tranquillity of the Sun's atmosphere, Egon von Oppolzer 581
some attempts to photograph the solar corona without an eclipse, Geo. E. Hale 662
a new method for mapping the spectra of metals, Henry Crew and Robert Tatnall 741
the astigmatism of Roland's concave gratings, Dr. J. L. Sirks 763
selecting suitable nights for observing planetary spectra, W. W. Campbell. (note) 860
the exterior nebulosities of the Pleiades, E. E. Barnard 768
the physical construction of the planet Jupiter, G. W. Hough 89
the forms of the discs of the satellites of Jupiter, E. E. Barnard 272
two great protuberances, J. Fenyi, S. J 122
the new star in Norma, E. C. Pickering 40
Auriga, H. C. Vogel, 48, (notes) 66, 136; H. Seeliger 142
the visual appearance of Nova Aurigæ, William Huggins 314

the spectrum of β Lyræ, H. C. Vogel.. .....358, 562
the influence of the slit-width on the appearance of comet spectra, H. Kayser, 367; (note)..... 399
Operation of chronograph, Electrical clock corrections for the—G. W. Hough 184
Oppolzer, Egon von, On Brester's views as to the tranquillity of the Sun's atmosphere..... 581
Optical instruments, Theory of—by Dr. Czapski (note)..... 241
works, Mr. Brashear's new—(note)..... 700
Orbit of the companions of Sirius (note)..... 82
α Centauri, Dr. See's researches on—(note)..... 256
Binary stars, Graphical method for determining the apparent—C. P. Howard 425
9 Argus—S. W. Burnham... 294
the companion of Algol (note)..... 516
the Binary star OΣ (224)—J. E. Gore..... 559
the 5th satellite of Jupiter (note)..... 781
Orion nebula, Note on the spectrum of the—W. W. Campbell (note)..... 695
Dr. Huggins' 1888 photograph of the spectrum of the great nebula in—G. E. Hale (note)..... 696
Spectra of the great nebula in—and other well-known nebulæ, W. W. Campbell.....384, 494
nebula, On the spectra of the—and the Orion stars, James E. Keeler..... 476
Red fringe to the—(note)..... 504
Note on the spectrum of the great nebula in—William Huggins..... 568
On the photographic spectrum of the great nebula in—J. Norman Lockyer 574
The great photographic nebula of—encircling the belt and Theta nebula. E. E. Barnard..... 811
Oxford, Professor Turner in the Savelian chair at—(note)..... 532
Oxygen in the atmosphere of the Sun, Is there—J. Janssen (note) 238; N. C. Duner.... 214
The line spectrum of—(note) 505; B. Hasselberg..... 760
Pallas—On the diameter of Ceres—and Vesta, E E. Barnard..... 341
Parkhurst, Henry M., Stellar photometry..... 652
Payne, W. W., Astronomical publications..... 23
Free public Observatories..... 110
Peculiar spectra, Stars having—M. Fleming..... 501
Periodic time and distance of Jupiter's 5th satellite, E. E. Barnard..... 556
Periodicities of the sunspots, Mechanical causes of the formation, motion and—J. M. Schaeberle..... 278
Perseid radiant, W. H. S. Monck 344; (note), 782; W. F. Denning (note)..... 872
Perseids of August, Radiant of—(note)..... 600
Peters-Borst star catalogue (note)..... 417
Periodicity of sunspots, Mechanical causes of—J. M. Schaeberle..... 278
Phases and aspects of the Moon for February 1894, 76; March 1894, 162; April 1894, 254; May 1894, 320; June 1894, 409; July and August 1894, 509; September and October 1894, 592; November 1894, 702; December, 1894, 777; Jan., 1995..... 865
Phenomena during the year 1894. H. C. Wilson..... 70
of satellites during 1894 (note)..... 73
of Jupiter's satellites (see Jupiter's satellites).
extraordinary—(note)..... 172

Philippine islands—Observatory at Manita—(note) 85
Photographic chart of the heavens, *Observatory*, Dec. 1893 20
chart of the sky, H. C. Wilson (note) 260
determination of stellar motions, E. C. Pickering 521
telescope of the Potsdam observatory—(note) 81
investigations of Captain Abney (note) 241
spectrum of the great nebula in Orion, On the—J. Norman Lockyer 574
nebulosities and star clusters connected with the milky way, E. E. Barnard 177
Photograph of the Pleiades (note) 412
the solar corona without an eclipse, On some attempts to—Geo. E. Hale 662
of the Pleiades and two asteroids, H. C. Wilson 192
of the Pleiades, Reproduction of the—made at Goodsell observatory by H. C. Wilson (frontispiece) 329
of Swift's nebula in Monoceros N. G. C. 2237, E. E. Barnard 642
of M 8 and the trifid nebula, E. E. Barnard 791
Photographs of a remarkable comet, E. E. Barnard 789
of recent total Eclipse, British (note) 82
of the corona of the total solar eclipse April 16, 1894, by Professor Schæberle (note) 169
of Gale's comet 1894, E. E. Barnard 421
Reproduction of astronomical—(note) 315
A collection of astronomical—G. E. Hale (note) 693
Photography, Electric control of equatorials in—W. C. Gurley 641
Progress of astronomical—(note) 783
of meteors, Instrument for—W. L. Elkin 626
The progress of astronomical—(note) 699
Photograpy of stellar spectrum, the use of the short-focus camera in—W. W. Campbell, J. E. Keeler (note) 857
Photometric catalogue of Harvard college observatory (notes) 586, 598
nebula of Orion encircling the belt and Theta nebula, E. E. Barnard 811
observations, Chandler's criticism of—at Harvard (notes) 399, 416
Photometry, Stellar—Henry M. Parkhurst 652
Physical constitution of the planet Jupiter. G. W. Hough 89
society of Toronto, Canada, Astronomical and—(notes) 174, 262, 327
Pickering, E. C., A new star in Norma 40, 398
Photographic determination of stellar motions 521
W. H., Telescope mountings and domes 1
Melting of polar caps of Mars 308
The forms of the discs of Jupiter's satellites 423
The seas of Mars 553
Schiaparelli's latest views regarding Mars 632
Recent observations of Jupiter's satellites 728
A study of Nova Aurigæ and Nova Normæ 201
Pikes Peak, The sky from—Garrett P. Serviss (note) 150
Planetary spectra, On selecting suitable nights for observing—W. W. Campbell (note) 860
Planets for 1894 (note) 71
Planet Jupiter, On the physical constitution of—G. W. Hough 89

Mars, Giovanni Schiaparelli..... 714
notes and tables for February 1894, 73; March 1894, 161; April 1894, 245; May 1894, 318; June 1894, 405; July and August 1894, 507; September and October 1894, 589; November 1894, 701 December 1894, 773; January 1895, H. C. Wilson..... 862
Platinum on glass mirrors, C. C. Hutchins (note)..... .....
Pleiades, Photograph of the—and two asteroids, H. C. Wilson..... 92
Reproduction of the photograph of the—made at Goodsell Observatory by H. C. Wilson (frontispiece)..... 329
Photograph of the—(note)..... 412
On the exterior nebulosities of the—E. E. Barnard..... 768
Planetary nebula SD—12° 1172, The—(note)..... 159
Polar cap of Mars, Melting of—W. H. Pickering 308; A. E. Douglass..... 738
radiation from the Sun, and its influence in forming the high and low atmospheric pressures of the United States. F. H. Bigelow..... 25
Potsdam observatory, The photographic telescope of the—(note)..... 81
Pulkowa double star measures, S. W. Burnham 354
Precession, Auxilliary quantities for computing—(note)..... 87
President of the Royal Astronomical Society on presenting the gold medal to Mr. S. W. Burnham, Address delivered by—..... 283
Prisms for stellar spectroscope, On a combination of—H. F. Newall..... 309
Prisms and lenses, Large rock-salt—(note)..... 240
apparatus, Results of an investigation of the aberration and atmospheric refraction made with a modified form of the Loewy—G. C. Comstock 329
Procyon, Variable proper motion of—S. W. Burnham..... 434
Professor Vogel on Nova Aurigæ (note)..... 150
Progress of astronomical photography (note)..... 699
Prominences, Auroræ and solar—M. A. Veeder (note)..... 597
Proper motion of the stars in the dumb bell nebula, E. E. Barnard..... 445
of double stars, S. W. Burnham..... 14
of Procyon, The variable—S. W. Burnham..... 434
Protuberances, On two great—J. Fenyi, S. J..... 122
Publications of the Lick observatory, Vol. II, 1894, Vol. III, 1894, (notes) 416, 784
Astronomical—W. W. Payne..... 23
Publisher's notices for February 1894, 176; March 1894, 264; April 1894, 328; May 1894, 420; June, 1894, 520; August 1894..... 604
Public observatories, Free—W. W. Payne..... 110
Pulkowa catalogue for 1885 (note)..... 597
Quantities for computing precession Auxilliary (note)..... 87
Quick adjustment of the equatorial (note)..... 171
Radiant of August Perseids (note)..... 600
The Perseid—W. . SH. Monck, 344; (note)..... 783
Radiation, The polar—from the Sun, and its influence in forming the high and low atmospheric pressures of the United States, F. H. Bigelow 25
of heated gases, The—Robert Tatnall (notes)..... 153, 587
from sun spots, The thermal—W. E. Wilson..... 378
of heated gases, Experiments on the—(note)..... .....
Recent observations of the satellites of Jupiter. Edward S. Holden, 356; E. E. Barnard, 438; W. H. Pickering..... 728
Red fringe to the Orion nebula (note)..... 504
spot on Jupiter (see Jupiter).

Refractive index of liquid air (note) 64
Refraction of light, Results of an investigation of the aberration and atmospheric—made with a modified form of the Loewy prism apparatus. G. C. Comstock 329
Remarkable spectra, Stars with—(note) 159
Reorganization of the U. S. Naval Observatory (note) 707
Researches on the spectra of the metals by Professor Hasselberg (note) 585
Region of Lacus Solis on Mars, J. M. Schaeberle 644
Ritchie, Jr., John, Error in sending discovery of Algol variable (note) 786
Rings of Saturn (note) 260
Rock-salt prism and lenses, Large (note) 240
The dispersion of flourite and—(note) 772
Rollins, William—Long focus telescopes 199
Roman college, Solar observations at the—in 1893, P. Tacchini (note) ..... 240 and during fourth quarter 1893, 312; third and fourth quarters 1893, 503; first quarter 1894 (note) 588
Rowland's concave gratings, On the astigmatism of—J. L. Sirks 763
Royal Astronomical Society, E. E. Barnard's present to—(note) 783
Royal Irish Academy, Transactions of—(note) 779
Runge, C., On a certain law in the spectra of some of the elements 128
Safford, T. H., The Pulkova catalogue for 1885 (note) 597
Sale of Astronomy and Astro-Physics (note) 871
Satellite of Neptune, F. Tisserand 291
Satellites during 1894, Phenomena of—(note) 73
of Jupiter, Recent observations of the—E. S. Holden, 356; W. H. Pickering, 728; E. E. Barnard 438
Saturn, Rings of—(note) 260
Preliminary note on the observations of—with the 36-inch equatorial. E. E. Barnard 557
Saturn's satellites, Elongation of—for February, 1894, 78; March, 1894, 166; April, 1894, 252; May, 1894, 321; June, 1894. 404
Savilian chair at Oxford, Professor Turner in—(note) 324
Schaeberle's photographs of the total solar eclipse April 16, 1894 (note) 169
Schaeberle, J. M., Mechanical causes of the formation, motion and periodicity of sunspots 278
A cometary structure in the corona of April 16, 1893 307
Region of Lacus Solis on Mars 644
Discovery of comet *b* 1893 170
Scheiner, J., The temperature of the surface of the fixed stars and of the Sun, compared with that of terrestrial sources of heat 569
Scheiner's spectral analyse der Gestirne (note) 596
Schiaparelli, Giovanni, The planet Mars 714
Schiaparelli's map of Mars (frontispiece) 605
latest views regarding Mars, W. H. Pickering 632
Sciences, New York Academy of—(notes) 88, 415
Chicago Academy of—Section of Mathematics and Astronomy (see Academy of Sciences at Chicago) 87
Scientific terms wanted, New—(note) 63
Section of Mathematics and Astronomy (see Academy of Sciences at Chicago). 87
Seeliger, H., On the new star in Auriga 142
Professor, The quadruple star ζ Cancri 802

Seas of Mars, W. H. Pickering 553
The solar image reflected in the—(note) 257
See's researches on the orbit of α Centauri (note) 256
See, T. J. J., Feb. 1894, Meeting of the Chicago Academy of Sciences, Report— 263
Report of March meeting 326; April meeting 419
Focus of center of gravity for a homogeneous ellipsoid of revolution 627
Orbit of the companion of Sirius (note) 82
Dec. meeting of Chicago Academy of Sciences, Reported—88; Jan. 1894 173
Sensitometer, A convenient—(note) 699
Sensitiveness of dry plates, The change of—G. W. Hough (note) 153
Serviss, Garrett P., The sky from Pike's Peak (note) 150
Shooting stars, Cometary—H. A. Newton 196
Simple method of mounting an equatorial axis on ball bearings, F. L. O. Wadsworth 723
Short-focus camera in spectrum photography, The advantage of the—J. E. Keeler (note) 772
The use of the—W. W. Campbell, James E. Keeler (note) 860
Sirks, J. L., On the astigmatism of Rowland's concave gratings 763
Sirius, Orbit of companion of—(note) 82
Sky from Pike's Peak, The—Garrett P. Serviss 150
Sky, Photographic chart of—(note) 260
Slit-width, On the influence of—on the appearance of comet spectra, H. Kayser, 367; (notes) 399, 505
Small nebula at M 57. Eugen von Gothard 190
Solar atmosphere, On Brester's views as to the tranquillity of the—A. Brester, Jr 849
corona, On some attempts to photograph the—without an eclipse. Geo. E. Hale 662
faculæ, The—G. E. Hale 113
prominences, auroræ and—M. A. Veeder (note) 597
image reflected in seas of Mars (note) 257
observations at the Royal Roman college during the first quarter 1894. P. Tacchini (note) 588
magnetic influence, West Indian hurricanes and—H. A. Hazen 105, 443
prominence, Observations of—and reversal of the D_3 line. W. E. Woods (note) 159
observations at the Roman college in 1893. P. Tacchini (note), 244; same during fourth quarter, 1893, 312; during third and fourth 1893. 503
work, Mr. Hadden's—(note) 317
magnetic influence, West Indian hurricanes and—Frank H. Bigelow 441
prominences, Auroræ and—(note) 597
system, On the magnitude of—Wm. Harkness 605
Spectra of the great nebula in Orion and other well-known nebulæ, W. W. Campbell 384, 494
of the Orion nebula and the Orion stars, James E. Keeler 476
Stars having peculiar—M. Fleming 501
of comets *b* and *c*, 1893, Note on the—W. W. Campbell 571
of metals by Professor Hasselberg, Researches on the—(note) 585
Professor Lockyer's researches on stellar—J. E. Keeler (note) 59

XUM

of some of the elements, On a certain law in the—C. Runge 128
Notes on stellar—(note) 158
Stars with remarkable—(note) 159
of comets, Note on the—H. Kayser 204
On the influence of the slit-width on the appearance of comet—H. Kayser, 367; also (notes) 399, 505
The nature of comet—(note) 586
of metals, A new method for mapping the—Henry Crew and Robert Tatnall 741
The infra--E. P. Lewis and E. S. Ferry 747
Spectralanalyse der Gestirne, Frost's translation and revision of die—James E. Keeler 688
Publications of—(note) 596
Spectroscopic investigations, Monsieur Cornu's, G. E. Hale (note) 57
investigations of Mr. George Higgs, G. E. Hale (note) 151
Spectroscope, On a combination of prisms for stellar—H. F. Newall 309
for the Lick observatory, New star—(note) 401
Spectroscopes, Fixed-arm—F. L. O. Wadsworth 835
Spectroheliograph for the Yerkes telescope, G. E. Hale (note) 64
Spectroscopy at Stonyhurst college observatory, G. E. Hale (note) 58
Spectrum of Mars, The—W. W. Campbell 752
of oxygen, On the line—B. Hasselberg 760
of Mars, Note on the—William Huggins (note) 771
photography, The advantage of the short-focused camera in—J. E. Keeler (note) 772
of the chromosphere, The appearance of D_3 line in the—(note) 584
of α Herculis, T. E. Espin 651
Magnesium—as an index to the temperature of the stars, J. E. Keeler 660
the Orion nebula, Note on the—W. W. Campbell (note) 695
Great nebula in Orion, Dr. Huggins' 1888 photograph of the—G. E. Hale (note) 696
of Nova Aurigæ, Mr. Campbell on the accuracy of his measures in the—(note) 66
of β Lyræ, On the—H. C. Vogel (notes) 584, 562, 358
of comet *b* 1894 (Gale) (note) 504
of oxygen, The line—(note) 505
of the great nebula in Orion, Note on the—William Huggins 568
of the great nebula in Orion, Note on the photographic—J. Norman Lockyer 574
changes in β Lyræ, J. Norman Lockyer 575
photography, The use of the short-focus camera in stellar—W. W. Campbell, James E. Keeler (note) 860
Sprague, R., Possibly a new double star (note) 417
Star catalogue, The Peters-Borst—(note) 417
clusters connected with the milky way, Photographic nebulosities and—E. E. Barnard 177
names and meanings (note) 788
measures, The Poulkowa double—S. W. Burnham 354
A new—in Norma, E. C. Pickering 40
On the new—in Auriga, H. C. Vogel, 48; (notes) 66, 136
On the new—in Auriga, H. Seeliger 142

New variable—(note)..... 159
in Norma, Observations of the new—W. W. Campbell..... 311
spectroscope, new—for the Lick Observatory (note)..... 401
Stars, The magnesium spectrum as an index to the temperature of the—J. E. Keeler..... 660
New—(note)..... 63
New variable—(note)..... 63
with remarkable spectra (note)..... 156
The Wolf-Rayet—W. W. Campbell..... 448
On the spectra of the Orion nebula, and the Orion—J. E. Keeler..... 476
having peculiar spectra..... 501
The temperature of the surface of the fixed—and of the Sun compared with that of terrestrial sources of heat, J. Scheiner..... 569
Proper motion of double—S. W. Burnham..... 14
Two new variable—M. Fleming..... 195
Cometary shooting—H. A. Newton..... 196
in dumb bell nebula, Proper motion of—E. E. Barnard..... 445
Steinheil, Dr. Adolph, Obituary notice..... 112
Stellar motions, Photographic determinations of—E. C. Pickering..... 521
spectra, Professor Lockyer's researches on—J. E. Keeler (note)..... 59
spectra, Notes on—(note)..... 158
spectrum photography, The use of the short focus camera in—W. W. Campbell, J. E. Keeler (note)..... 857
photometry, Henry M. Parkhurst..... 652
spectroscope, On a combination of prisms for—H. F. Newall..... 309
Stonyhurst College Observatory, Spectroscopy at—G. E. Hale (notes)..... 58, 316
Structure in the corona of April 16, 1893, Cometary—J. M. Schaeberle..... 307
Sun, Distribution of the heat of—W. H. S. Monck..... 823
Annular eclipse of—April 5, 1894..... 250
The British photographs of the recent total eclipse of the—(note)..... 82
Is there oxygen in the atmosphere of the—J. Janssen (note) 238; N. C. Duner..... 215
A short review of my theory of the—A. Brester, Jr..... 218
Experimental investigations on the effective temperature of the—W. E. Wilson and P. L. Gray..... 382
The temperature of the surface of the fixed stars and of the—compared with that of terrestrial sources of heat, J. Scheiner..... 569
Sun's atmosphere, On Brester's views as to the tranquillity of the—Egon von Oppolzer..... 581
Sunspot observations at Goodsell Observatory, H. C. Wilson..... 293
Sunspots, Mechanical causes of the formation, motion and periodicity of—J. M. Schaeberle..... 278
The thermal radiation of—W. E. Wilson..... 378
Survey office, United States coast—(note)..... 414
Swift's nebula in Monoceros, Photograph of N. G. C. 2237—E. E. Barnard.... 642
Tacchini, P., Solar observations at the Roman College in 1893 (note)..... 244
Same during fourth quarter 1893, 312; third and fourth 1893, 503; first 1894 (note)..... 588
Tatnall, Robert R., The radiation of heated gases (note)..... 153
and Henry Crew, On a new method for mapping the spectra of metals..... 741
Taylor, H. Dennis, A new triple achromatic object-glass (note)..... 696

Telescopes, Chromatic aberration of—James E. Keeler (note) 157
Test objects for small— 168
Long focus—Wm. Rollins 199
Telescope mountings and domes, W. H. Pickering 1
of the Potsdam Observatory, The photographic—(note) 81
Apparatus for electrical control of—(frontispiece) 265
for the Illinois Wesleyan University (note) 784
for Greenwich Observatory, New—(note) 317
Another great—(note) 700
for the Cape Observatory, A large—(note) 700
Spectroheliograph for the Yerkes—G. E. Hale (note) 64
Temperature of the Sun, Experimental investigations of the effective—W. E. Wilson and P. L. Gray 382
of the surface of the fixed stars and of the Sun, compared with that of terrestrial sources of heat, J. Scheiner 569
of the stars, The magnesium spectrum as an index to the—J. E. Keeler 660
Terrestrial sources of heat, The temperature of the surface of the fixed stars and of the Sun, compared with that of—J. Schiner 569
Test objects for small telescopes 168
The Astrophysical Journal, Geo. E. Hale 831
Theory of the Sun, A short review of my—A. Brester, Jz 218
of optical instruments by Dr. Czapski (note) 241
Thermal radiation from sunspots, W. E. Wilson 378
Thome, John M., The National Argentine Observatory 8
Time and distance of the satellite of Jupiter, Periodic—E. E. Barnard 556
Tisserand, F., The satellites of Neptune 291
Tranquillity of the Sun's atmosphere, On Brester's views as to the—A. Brester, Jr., 849; Egon von Oppolzer 581
Transactions of the Royal Irish academy (note) 779
Transit of Mercury, Nov. 10, 1894, Observations of—at Lowell, Davidson, Chabot, Halsted, Agricultural college [Brookings, S. D.], Leander, McCormick and Goodsell observatories 865, 869
of Mercury, Nov. 10, 1894, 704; [notes] 70, 779
Trifid nebula and M8, Photograph of—E. E. Barnard 791
Turner, Professor in the Savilian chair at Oxford [note] 324
20-inch equatorial for Chamberlin observatory. H. A. Howe 709
United States Coast Survey Office (note) 414
Naval Observatory, Reorganization of—(notes) 601, 707
Unit of velocity in the line of sight, E. B. Frost (note) 160
Uranus' satellites, Elongation of—for May 1894, 330; June 1894, 408; July and August 1894 510
Uranus, Preliminary note on the observations of—with the 36-inch equatorial, E. E. Barnard 557
Variable proper motion of Procyon, S. W. Burnham 434
stars, Maxima and minima of—for April 1894, 254; for May 1894, 321; for June 1894, 408; for July and August 1894, 511; for September and October 1894, 593; for November 1894, 702; for December 1894 777
stars of the Algol type, Minima of—for February 1894, 79; for March 1894, 167; for April 1894, 253; for May 1894, 322; for June 1894, 409; for July and August 1894, 510; for September

and October 1894, 592; for November 1894, 703; for December 1894 ... 778
stars, Two new—M. Fleming ... 195
stars, New [note] ... 63
stars, Chandler on observations of—at Harvard college observatory [note] ... 325
star, [note] ... 159
star in Andromeda, Anderson's—[note] ... 317
star of the Algol type, Discovery of a new— ... 702
star of the Algol type ... 786
Veeder, M. A., [note] ... 597
The aurora of March 30, 1894 (note) ... 401
North Greenland aurora observations [note] ... 779
Variation of gravity with altitude [note] ... 404
Velocity, Unit of—in the line of sight. E. B. Frost [note] ... 160
Vesta, On the diameters of Ceres, Pallas and—E. E. Barnard ... 341
Visual appearance of Nova Aurigæ, On the—William Huggins ... 314
Vogel, H. C., On the new star in Auriga ... 48, 136
spectrum of β Lyræ ... 358, 562
Volume XXXV of the Astronomical Observatory of Harvard college [note] ... 171
Wadsworth, F. L. O., Electric control and governors for astronomical instruments ... 265
Some new forms of double motion mechanism ... 527
A simple method of mounting an equatorial axis on ball bearings ... 723
Fixed arm spectroscopes ... 835
Washington meridian circle work (note) ... 415
Wendell, O. C., Ephemeris of comet *c* 1893 for January 1894 ... 80
Wesleyan University of Illinois, New telescope for—(note) ... 784
West Indian hurricanes and solar magnetic influences, H. A. Hazen ... 105, 443
Same, Frank H. Bigelow ... 441
Wilson, H. C., Phenomena during the year 1894 ... 70
Photograph of the Pleiades and two asteroids ... 192
Sunspot observations at Goodsell Observatory ... 293
Reproduction of a photograph of the Pleiades made at Goodsell Observatory by—[frontispiece] ... 326
Wilson, W. E., The thermal radiation from sun-spots ... 378
Experimental investigations on the effective temperature of the Sun, made at Daramona, Streete, Co., Westmeath ... 382
Wolsingham observatory, Report of—for the year 1893 [note] ... 240
Woods, W. E., Observations of a solar prominence and reversal of the D_3 line. 159
Wolf, Dr. Rudolf—Obituary notice ... 112
Wolf-Rayet stars, The—W. W. Campbell ... 448
Yale Observatory, Instrument for the photography of meteors for the—W. L. Elkin ... 625
Year 1894, Phenomena of—H. C. Wilson ... 70
Eclipses, transit of Mercury occultations ... 70
Planets ... 71
Comets ... 72
Phenomena of satellites ... 73
Yerkes telescope, Spectroheliograph for—G. E. Hale (note) ... 64
Young, C. A., Observations of the transit of Mercury Nov. 10, 1894 (note) ... 868
ζ Cancri, the quadruple star—Professor Seeliger ... 280

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

[Continuing Astronomy and Astro-Physics.]

EDITORS.

GEORGE E. HALE, Director of the Yerkes Observatory
JAMES E. KEELER, Director of the Allegheny Observatory

ASSISTANT EDITORS.

J. S. AMES, Johns Hopkins University
HENRY CREW, Northwestern University
W. W. CAMPBELL, Lick Observatory
E. B. FROST, Dartmouth College
F. L. O. WADSWORTH, University of Chicago

ASSOCIATE EDITORS.

M. A. CORNU, École Polytechnique, Paris.
C. S. HASTINGS, Yale University.
N. C. DUNÉR, Astronomiske Observatorium, Upsala.
A. A. MICHELSON, University of Chicago.
WILLIAM HUGGINS, Tulse Hill Observatory, London.
E. C. PICKERING, Harvard College Observatory.
P. TACCHINI, R. Osservatorio del Collegio Romano, Rome.
H. A. ROWLAND, Johns Hopkins University.
H. C. VOGEL, Astrophysikalisches Observatorium, Potsdam.
C. A. YOUNG, Princeton University.

PUBLISHED BY

The University of Chicago.

Wm. Wesley & Son, 28 Essex St. Strand, London, are sole foreign agents.

THE ASTROPHYSICAL JOURNAL.

THE UNIVERSITY OF CHICAGO, ...189...

University Press Division, Chicago U. S A.

Enclosed find $..... for which please send **The Astrophysical Journal,** *for..... .....year ....., beginning with.....number to the following address:*

SUBSCRIPTION RATES
(Including Postage)

United States, Canada and Mexico, one year (10 numbers), $4.00.
Other Countries in the Postal Union, $4.50, or 18 shillings.
All European subscriptions should be addressed to WM. WESLEY & SON, 28 Essex St., Strand, London.

Name.....
Street No.....
Town or City.....
State.....

THE ASTROPHYSICAL JOURNAL is published ten times a year, on the first day of every month except July and September. Money should be sent by Post-Office Order, or Bank Draft on Chicago or New York, made payable to THE UNIVERSITY OF CHICAGO, Chicago, Illinois.

C. A. Steinheil Söhne,

Optical and Astronomical Works,

Munich, Bavaria.

[Established 1855.]

Manufacturers of Instruments for Astronomical and Physical Research, Telescopic Objectives of every size, Oculars, Magnifiers (aplanatic), Prisms, Telescopes for Visual and Photographic Purposes; Parallel Plates, Spectrum Apparatus (the first ones for Messrs. Kirchhoff and Bunsun were made here.)

Catalogues (in English) may be had post-paid on application.

The Sidereal Messenger,

COMPLETE IN TEN VOLUMES

Of about 320 pages each.

This publication is a record of Astronomical Events between the years 1882 and 1891 inclusive.

COMPLETE SETS

In Pamphlet form will now be sold at

Greatly Reduced Price.

TEN VOLUMES FOR ONLY $15.

Complete Sets are offered at these low rates, as but a few more can be furnished.

Orders will be filled promptly and sent carriage prepaid on receipt of the price named above. Address,

Wm. W. PAYNE, Publisher,

Northfield, Minn.

Volume II, Number 2.

THE PHYSICAL REVIEW.

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS,

CONDUCTED BY

EDWARD L. NICHOLS AND ERNEST MERRITT.

IX.

NOVEMBER-DECEMBER 1894

CONTENTS.

Frontispiece: Portrait of Professor von Helmholtz.
Studies of the Lime Light.—Edward L. Nichols and Mary L. Crehore. 161
A Study of the Residual Charges of Condensers and their Dependence upon Temperature.—Frederick Bedell and Carl Kinsley. 170
A General Theory of the Glow-Lamp. II.—H. S. Weber..... 197
Minor Contributions: (1) On the Thermal Conductivity of Cast Iron as a Function of Temperature. *I. Thornton Osmond.* (2) On Some Magnetic Characteristics of Iridium. *S. H. Brackett*..... 211
Notes: (1) Hermann von Helmholtz. (2) The American Association for the Advancement of Science..... 222
New Books: *Greenhill:* A Treatise on Hydrostatics. *Hellmann:* Schneekrystalle Beobachtungen und Studien. Recent Text-books in Heat. *Nichols:* A Laboratory Manual of Physics and Applied Electricity. *Ram:* The Incandescent Lamp and its Manufacture..... 229

COPYRIGHT, 1894, BY MACMILLAN & CO.

PUBLISHED FOR CORNELL UNIVERSITY.

MACMILLAN & COMPANY,

NEW YORK, LONDON.

BERLIN: MAYER AND MUELLER.

JOHN BYRNE'S
Astronomical and Terrestrial

Telescopes.

Of 3, 4, 5, 6 inches and larger apertures.

Short Focus and Brilliant Light.

Inimitable for Perfection of Figure, Sharpness of Definition, and Accuracy of Color Correction.

Correspondence with Educational Institutions and Colleges invited.

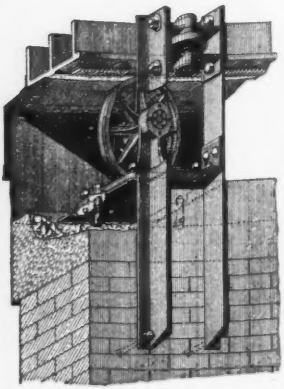
Send for Catalogue to

Gall & Lembke

21 UNION SQUARE, NEW YORK CITY.

DOMES FOR ASTRONOMICAL OBSERVATORIES.

BUILT ON THE HOUGH SYSTEM



Possess the following advantages over all others:

Minimum weight of rotating parts.

Perfect alignment, by the use of adjustable, stationary, roller-bearing wheels; consequent ease of rotation, and lateral stability under all conditions.

An opening continuous from horizon to zenith.

A shutter that closes weather tight, will not bind, and can be quickly and easily operated.

Simplicity of construction, durability and cheapness.

The roller-bearing wheels and the shutter can be applied to existing domes, with slight alterations and at moderate expense.

mes built on the new method may be seen at the Dearborn Observatory, Northwestern University, Evanston, Illinois at the Observatory at Denver, Colorado, and at Cincinnati, Ohio.

For further particulars and estimates of cost, address,

C. L. STROBEL, C. E.,
525 Home Insurance Building, Chicago, Ill.

THE

E. Howard Watch and Clock Co.

383 WASHINGTON STREET, BOSTON,
41 MAIDEN LANE, NEW YORK,
34 WASHINGTON STREET, CHICAGO.

MANUFACTURERS OF

Astronomical Regulators

REGULATORS OF PRECISION,

AND ❋ FINE ❋ WATCHES.

To any of our regulators we attach devices for the transmission of electrical currents for operating chronographs, sounders (indicating the time of the standard regulator), or for synchronizing secondary clocks when desired.

These electrical transmitting devices can be attached to our No. 89 regulator, which is especially constructed to meet the wants of the railroad service; and the almost absolute certainty and regularity of the performance of these regulators make them particularly desirable as secondary standards for the railroad service.

To our Astronomical Regulators we apply either Dennison's Gravity or the Graham Dead-Beat escapement. These regulators are made in several grades, thereby meeting the wants of Institutions having ample means for the purchase of the most elaborate form of time-keeping instruments, as well as newly established Institutions with limited means to invest in a regulator.

Our watches are second to none in the world as time-keepers and the manner of their construction is such that they are less liable to injury from improper handling, than any other watch now in the market.

We respectfully solicit correspondence from Corporations, Institutions and individuals contemplating the purchase of a Regulator, regardless of the grade.

ALVAN CLARK & SONS,

CAMBRIDGEPORT, MASS.

MANUFACTURERS OF

Astronomical Telescopes

WITH IMPROVED

EQUATORIAL MOUNTINGS.

SIZES FROM FOUR-INCH APERTURE TO THE LARGEST EVER ORDERED.

Send for Photographs

Of our Portable Eqautorials or 5 and 6-inch fixed, with Accessories, The best to be had for Educational and Amateur work.

Terrestrial Telescopes for Private Residcenes.

The performance of our instruments, famous the world over, is their own greatest recommendation. An experience of nearly a half century in the art of telescope making, enables us to apply a degree of skill and judgment to our work which make our objectives

UNRIVALLED IN EXCELLENCE.

AMONG OUR TELESCOPES ARE:

The Lick Refractor, 36-inch.
Pulkowa Refractor, 30-inch.
Washington Refractor, 26-inch.
University of Virginia, 26-inch.
Princeton Refractor, 23-inch.
Denver Refractor, 20-inch.
Chicago Refractor, 18.5-inch
Rochester Refractor, 16-inch.

XUM

MESSRS. T. COOKE & SONS have the honor to announce that they are now in a position to supply a PERFECTLY ACHROMATIC ASTRONOMICAL OBJECTIVE (H. D. Taylor's Patent), for which they claim the following remarkable advantages over any hitherto constructed:—

1--Perfect freedom from Secondary Spectrum; no more color being visible than in a Reflecting Telescope.

2--Equally available for either Photographic or Visual purposes without reversing of lenses or other adjustment.

3--The angular extent of its field of good definition exceeds that obtained in the 13-in. Standard Photographic Objective prescribed at the International Astrophotographic Congress.

A description of this Objective has been given by Mr. Taylor (Optical Manager to Messrs. T. Cooke & Sons), before the Royal Astronomical Society, at its meeting on 9th March, 1894.

It is a Triple Objective constructed of three varieties of Jena glass, of which Messrs. Cooke guarantee the durability.

The prices are as follows:—

Inch.	£	Inch.	£
12	550	5	57
10	350	4½	44
9	265	4¼	37
8	195	4	32
7	135	3¾	27
6½	110	3½	22
6	90	3¼	18
5½	75	3	15

Larger discs have not so far been obtainable, but Messrs. Cooke hope shortly to be in a position to construct objectives up to 24-in. diameter.

T. COOKE & SONS,

Buckingham Works, - York, - England.

St. Louis University, St. Louis, Mo.
Messrs. Poole Bros: *June 9th, 1893.*

Dear Sirs:—Planisphere and Handbook received in good order yesterday. Many thanks for your kindness and dispatch.

I am very much pleased with both and do not hesitate to say that they are the finest works of the kind I have ever seen. The fine illustrations of the Handbook, their number and "clean cut" impression, not to mention the wealth of information connected with them, make one wonder that such a valuable work can be offered at so low a price. Respectfully,

WM. F. RIGGE, S. J.,
Professor Astronomy.

EASY STEPS TO THE STARS

POOLE BROTHERS' CELESTIAL PLANISPHERE

A CHART OF THE HEAVENS.

Designed to show the Student the places of the Constellations at any given moment.

For the use of Observers, the Publishers have for sale SPECIAL SHEETS of the PLANISPHERE printed on a suitable paper, so that the Student may make and keep a Record of any Celestial Phenomena of Special Interest, such as the Paths of Planets, Comets, Shooting Stars, etc.

Prepaid to any Address { **Single Sheets, 25 cents.** / **Per Dozen, $2.00.**

POOLE BROTHERS' CELESTIAL HANDBOOK

CONCISE AND ACCURATE.

Companion to the Celestial Planisphere and Explanatory of its uses, besides other desirable Astronomical Information for both the Amateur and the Advanced Student.

It is difficult to imagine how astronomy could be studied under more favorable auspices than with this Planisphere and the very elegantly illustrated descriptive Handbook accompanying it.—Scientific American, February 18th, 1893.

For Descriptive Circular and other information, address

POOLE BROTHERS,
316 Dearborn Street, CHICAGO, ILL.

WILLIAM WESLEY & SON,
AGENTS,
28 Essex Street, Strand, London, Eng.

XUM

Astronomical Instruments,

TELESCOPES,

TRANSITS,
MICROMETERS,
CHRONOGRAPHS,

Sidereal Clocks,
Driving Clocks,
Domes,
Observatories,

Spectroscopes, Microscope Stands, Micrometers for Microscopes.

OUR NEW 10-INCH EQUATORIAL.

Parties seeking anything in these lines will find it advantageous to address **Central Tenn. School of Mechanical Engineering,** *NASHVILLE, TENNESEE.*

BELOIT COLLEGE offers graduate and undergraduate students courses with the following

INSTRUCTORS AND AMPLE EQUIPMENT:

SMITH OBSERVATORY.
CHAS. A. BACON, M. A., Director and Professor of Astronomy.
GEO. E. HALE, B. S., Lecturer on Astro-physics.

PEARSON'S HALL OF SCIENCE.
T. A. SMITH, PH. D., Professor of Mathematics and Physics.
E. G. SMITH, PH. D., Professor of Chemistry and Mineralogy.
H. D. DENSINERE, M. A., Professor of Botany.
G. L. COLLIE, PH. D., Professor of Geology.

For information address President EATON, Beloit, Wisconsin.

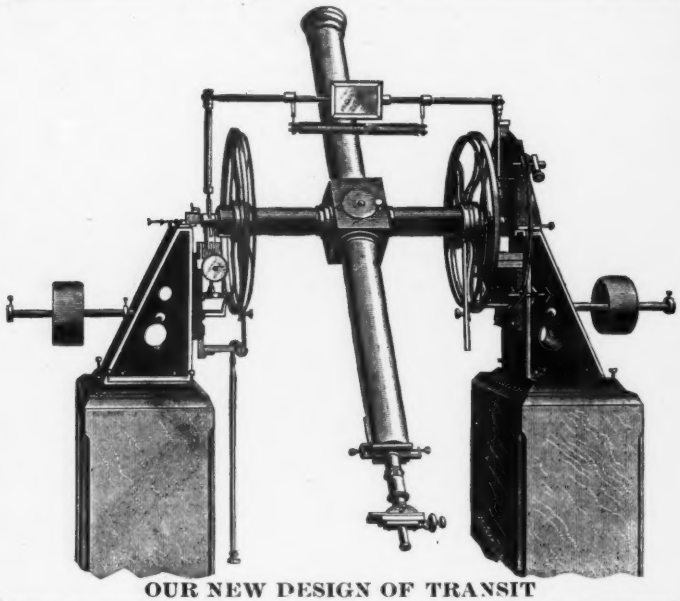
Wanted, a Telescope Mounting.

I wish to purchase an equatorial Mounting for an 8½-inch silver-on-glass reflector, slow motion in right ascension, with or without clock or circles. Correspondence solicited. F. A. L., 297 Bellfountain St., Indianapolis, Ind.

ON SALE.

(Owner giving up astronomical work) the 3-foot Common Reflector, with without dome complete, in perfect order. Mirror by Sir H. Grubb. Further particulars on application to

J. GLEDHILL, Bermerside Observatory, Halifax, England.



OUR NEW DESIGN OF TRANSIT

Parties seeking anything in this line will find it advantageous to address **Central Tenn. School of Mechanical Engineering.**

NASHVILLE, TENNESSEE.

CARLETON COLLEGE,

NORTHFIELD, MINNESOTA.

CLASSICAL, LITERARY, SCIENTIFIC, ECLECTIC
: : AND POST-GRADUATE COURSES.

THE ACADEMY—Preparatory and Special Courses.
THE SCHOOL OF MUSIC—Organ, Piano, Violin and Voice.
Instructions in Drawing and Painting, and in Stenography and Type-Writing.

All Departments Open to Both Gentlemen and Ladies.

Calendar for 1894-5.

Examinations to enter the Academy, the first afternoon of each term.
Examinations to enter the College, Sept. 4, 1894, and June 7, 1895.
Fall Term begins Wednesday, Sept. 5, and ends Thursday, Dec. 20, 1894.
Winter Term, Thursday, Jan. 3, to March 14, 1895.
Spring Term, Wednesday, March 27, to June 13, 1895.
Anniversary Exercises, June 8 to 13, 1895.
Monday is the regular Weekly holiday. Recitations are suspended also on all legal holidays.

JAMES W. STRONG, PRESIDENT.

XUM

XUM

GEO. N. SAEGMULLER

SUCCESSOR TO FAUTH & CO.,

WASHINGTON, D. C.

Manufacturer of all kinds of

Astronomical Apparatus.

Equatorials with the latest improvements.

Large Transits and Transit Circles with stationary, automatic Reversing and Anti-Friction Apparatus, arranged below the floor.

Portable Transits of entire new design.

Zenith Telescopes,

Chronographs,

Collimators and Meridian Marks.

Astronomical Clocks.

Cheap Astronomical Outfits, consisting of four-inch Equatorial, two-inch Astronomical Transit, Astronomical Clock and Chronograph.

Engineering Instruments. All kinds of Fixed and Portable Astronomical and the higher grades of engineering Instruments.

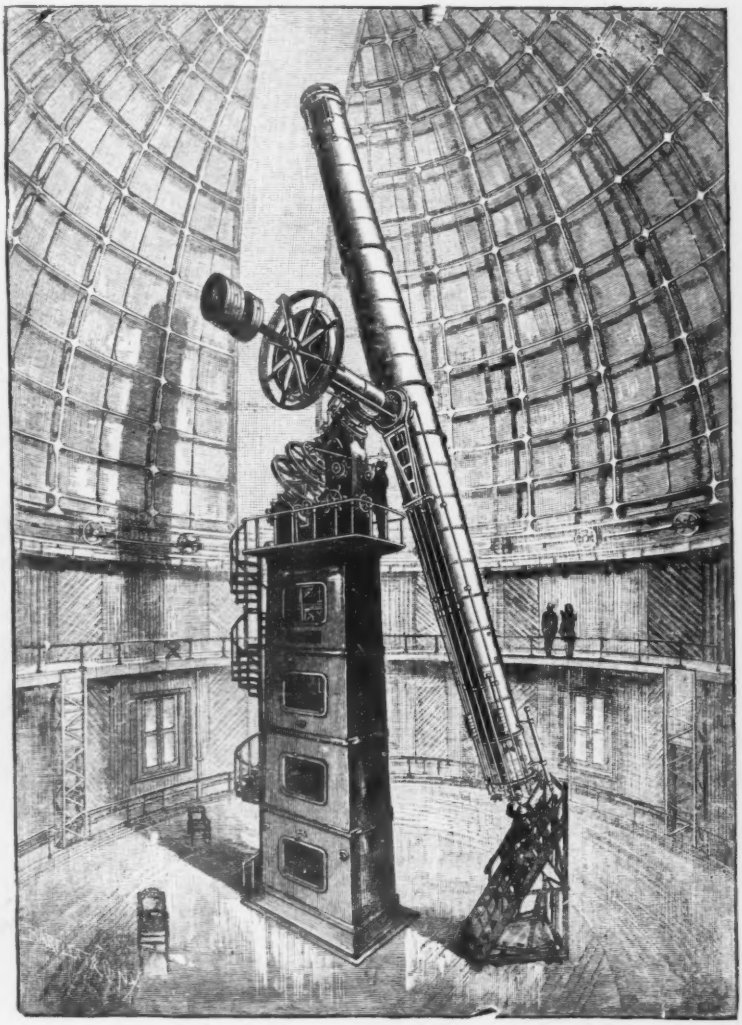
The Graduations made on our Automatic Dividing Engine cannot be surpassed in accuracy and beauty of lines.

Finely ground levels with curves up to 1800 feet.

Send for New Catalogue.

The Lick Telescope

APERTURE 36 INCHES.



ALSO ALL SMALLER SIZES

DESIGNED AND MADE BY

WARNER & SWASEY

CLEVELAND, OHIO, U. S. A.

Y

KUM